MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

VOL. LXXVII. FEBRUARY 9, 1917. No. 4

ANNUAL GENERAL MEETING.

Professor R. A. SAMPSON, M.A., D.Sc., F.R.S., PRESIDENT, in the Chair.

The Report of the Auditors of the Treasurer's accounts for the year 1916 was read, and is given on p. 286.

The Annual Report of the Council was partly read.

The Address was delivered by the President, after which the Gold Medal was handed to the Foreign Secretary, for transmission to Mr. Walter Sydney Adams, to whom it had been awarded for his investigations in Stellar Spectroscopy, including the determination of Absolute Magnitudes.

The President having appointed the Scrutineers, the Society proceeded to the ballot for Officers and Council for the ensuing year. The names of those elected are given on p. 411.

The thanks of the Meeting were given to the retiring President, Vice-Presidents, Secretary, and other members of Council, and also to the Auditors of the Treasurer's accounts and to the Scrutineers of the ballot.

Mrs. Louisa Petitot Freeman, 67 High Street, Oxford;
William Henry Pick, B.Sc. (Lond.), F.C.S., 141 Mare Street, Hackney, N.E.; and
J. G. E. G. Voûte, Royal Observatory, Cape of Good Hope,

were balloted for and duly elected Fellows of the Society.

The following candidate was proposed for election as a Fellow of the Society, the name of the proposer from personal knowledge being appended:—

James Bootherstone, 36 St. Anne's Road, Chorlton-cum-Hardy, Manchester (proposed by W. C. Jenkins).

Report of the Council to the Ninety-seventh Annual General Meeting of the Society.

The following table shows the progress and present state of the Society:—

	Patron	Honorary Members	Fellows		Associates	Total
			Compounders	Annual Subscribers		
1915 December 31	1	1	242	468	48	760
Since elected	...	...	+ 3	+26	+2	...
Deceased	...	...	−10	−12	−2	...
Resigned	...	...	...	− 8	...	...
Since compounded	...	...	...	...	...	...
Removed from list	...	...	...	− 8	...	...
1916 December 31	1	1	235	466	48	751

(Six Associates are also Fellows, and are therefore counted twice in the above table.)

Mr. Knobel's Account as Treasurer of the Royal

RECEIVED.

	£ s. d.	£ s. d.
Balances, 1915 December 31 :—		
At Bankers', as per Pass-book	157 8 3	
Cheques not credited till 1916	6 6 3	
In hand of Assistant Secretary on Petty Cash Account	8 8 2	
		172 2 8
Dividends :—		
£1,250 Metropolitan 3-per-cent. Stock ...	28 16 9	
£2,000 Swansea Corporation 3½-per-cent. Stock	55 2 6	
£3,500 East Indian Railway 3-per-cent. Debenture Stock	80 14 4	
£3,500 London and North-Western Railway 3-per-cent. Debenture Stock	85 19 4	
£4,000 Midland Railway 2½-per-cent. Debenture Stock	81 17 6	
£1,000 Lancashire and Yorkshire Railway 3-per-cent. Preference Stock	24 11 3	
£2,400 Gas Light and Coke Co. 3-per-cent. Debenture Stock	58 19 0	
£2,000 Commercial Gas Co. 3-per-cent. Debenture Stock	46 15 0	
£1,000 War Loan 4½-per-cent. Stock	33 15 0	
		496 10 8
Received on account of Subscriptions :—		
Arrears	154 7 0	
Annual Contributions for 1916	690 18 0	
,, ,, in advance	12 12 0	
Admission Fees	63 0 0	
First Contributions	46 4 0	
		967 1 0
Composition Fees		94 10 0
Sales of Publications :—		
At Society's Rooms	51 8 0	
At W. Wesley & Son's 107 2 7		
Less discount, 10 per cent. 10 12 8		
	96 9 11	
Herschel's Works: half share, received from the Royal Society	3 0 0	
		150 17 11
Grant from Trinity College, Dublin, towards cost of replacing goods destroyed by fire ...		10 0 0
Sales of Photographs		24 10 6
Income Tax refunded by Commissioners of Inland Revenue		84 19 8
Cheque outstanding		3 0 0
		£2,003 12 5

Examined and found correct.

(Signed) G. J. NEWBEGIN.
W. SHACKLETON.
J. JACKSON.

1917 *January* 10.

Astronomical Society, from 1916 *January* 1 *to December* 31.

PAID.

	£	s.	d.	£	s.	d.
Assistant Secretary: Salary	250	0	0			
,, ,, Editing Society's Publications	50	0	0			
Clerk: Salary	100	0	0			
Assistant Clerk: Salary	2	2	0			
				402	2	0
House Duty	2	12	6			
Fire Insurance	10	13	0			
Aircraft Insurance	10	8	0			
Insurance of stock at printers'	3	18	9			
Servants' Insurance	0	16	0			
				28	8	3
Printing, etc.:—						
Monthly Notices	525	19	11			
List of Fellows and Miscellaneous	67	4	3			
Photo-engraving, etc.	40	11	1			
				633	15	3
Reproduction of Photographs for sale:—						
Higgs' Atlas of the Solar Spectrum	11	1	10			
Other photographs	25	2	8			
Cases for Higgs' Spectra	1	2	6			
				37	7	0
Turnor and Horrox Fund: purchase of books for Library	13	13	2			
Binding books for Library	16	0	11			
				29	14	1
Expenses of Meetings	18	6	11			
Attendance to Lantern	3	10	0			
Time Signal: rental of wire	5	0	0			
				26	16	11
Subsn. to Bureau Internat. pour télégrammes astron.	2	6	0			
Telephone subscription	6	10	0			
Registration of telegraphic address	1	1	0			
Postage and telegrams	80	19	0			
Carriage of parcels	0	8	1			
Stationery and office expenses	15	15	0			
				106	19	1
House expenses; Allowance and sundry expenses	57	13	11			
Coal, Gas, and Electric Light	59	6	3			
Window blinds	8	19	6			
Sundry fittings and repairs	10	9	2			
Sundries	3	8	6			
				139	17	4
Expenses moving Society's telescope from Ashtead to Headley				20	0	0
Testimonial to Assistant Secretary				250	0	0
Lee and Janson Fund: Grants to Mrs. McDowell				12	0	0
Cheque-book and bankers' charges on cheques ...				0	12	8
Repayment to Assistant Secretary of amount due on Turnor and Horrox Fund Account ...				3	7	4
Balances, 1916 December 30:—						
At Bankers', as per Pass-book	298	12	6			
In hand of Assist. Sec. on Petty Cash Account	13	0	6			
,, ,, on Account of Turnor and Horrox Fund ...	0	19	6			
				312	12	6
				£2,003	12	5

Report of the Auditors.

We have examined the Treasurer's accounts of receipts and expenditure for the year 1916, and have found and certified the same to be correct. The cash in hand on 1916 December 31, including the balance at the Bank, etc., amounted to £312, 12*s.* 6*d.*

The funded property of the Society is the same as at the end of the previous year.

A certain amount of the stock of the Society's publications, which was at the printers', having been destroyed by a fire at Messrs. Neill's works, an insurance has been effected upon such stock as may be at the printers'.

The books, instruments, and other effects appear to be in a satisfactory condition. As was mentioned in the Auditors' report of last year, some of the instruments in the list appear to be of no practical value.

A list has been laid on the table of the names of those Fellows who are in arrear for sums due at the last Annual General Meeting of the Society, with the amount due against each Fellow's name.

(Signed) J. Jackson.
G. J. Newbegin.
Wm. Shackleton.

1917 *January* 10.

Gifts to the General Funds of the Society.

In 1836 John Lee, Esq., LL.D., gave the Advowson of the living of Hartwell; in 1844 he gave the Advowson of the living of Stone, Bucks. In 1879 these Advowsons were repurchased by his heir, Edward Lee, Esq., for £700.

The Lawson Bequest (1856): Henry Lawson, Esq., bequeathed to the Society the sum of £200, free of legacy duty.

The Carrington Bequest (1876): R. C. Carrington, Esq., F.R.S., bequeathed to the Society £2,000 Consols.

The Lambert Bequest (1877): C. J. Lambert, Esq., presented to the Society the sum of £500, free of legacy duty, being part of a sum of money bequeathed by his father, Charles Lambert, Esq., for scientific purposes.

The McClean Bequest (1905): Frank McClean, Esq., LL.D., F.R.S., bequeathed to the Society the sum of £2,000, free of legacy duty.

The Farrar Bequest (1906): The Rev. A. S. Farrar, D.D., bequeathed to the Society the sum of £100, free of legacy duty.

Trust Funds.

The Lee and Janson Fund: In 1834 John Lee, Esq., LL.D., gave £100, and in 1876 T. C. Janson, Esq., bequeathed £200, the interest to be given to the widow or orphan of a deceased Fellow. These amounts now stand in £334 10*s.* 9*d.* East Indian Railway 3-per-cent. Debenture Stock.

	£	*s.*	*d.*		£	*s.*	*d.*
1916 Jan. 1. Balance of Fund	47	0	1	1916. Grants to Mrs. McDowell	12	0	0
Dividends, East Indian Railway	10	0	9	1916 Dec. 31. Balance of Fund	45	0	10
	£57	0	10		£57	0	10

The Turnor Fund and the Horrox Memorial Fund: In 1853 the Rev. Charles Turnor, M.A., bequeathed a sum of £500, which now stands in £464 18*s.* East Indian Railway 3-per-cent. Debenture Stock. In 1876 the Society received a sum of £38 15*s.*, the unexpended balance of a fund collected for the purpose of erecting a memorial in Westminster Abbey to Jeremiah Horrox: to this the Society added the sum of £55 15*s.*, and the whole now stands in £103 6*s.* East Indian Railway 3-per-cent. Debenture Stock. The interest on these funds is to be used in the purchase of books for the Library.

	£	*s.*	*d.*		£	*s.*	*d.*
1916 Jan. 1. Balance of Fund	2	11	4	1916. Purchase of Books	13	13	2
1916. Dividends, East Indian Railway ...	17	1	0	1916 Dec. 31. Balance of Fund	5	19	2
	£19	12	4		£19	12	4

The Hannah Jackson (née Gwilt) Fund: In 1861 Mrs. Hannah Jackson (*née* Gwilt) gave £300 Consols, which now stands in £309 18*s.* 6*d.* East Indian Railway 3-per-cent. Debenture Stock; the interest to be given in medals or other awards in accordance with the terms of the Trust.

	£	*s.*	*d.*		£	*s.*	*d.*
1916 Jan. 1. Balance of Fund	35	2	5	1916 Dec. 31. Balance of Fund	44	8	5
1916. Dividends, East Indian Railway ...	9	6	0				
	£44	8	5		£44	8	5

Assets and Present Property of the Society, 1917 January 1.

	£ s. d.	£ s. d.
Balances, 1916 December 30 :—		
At Bankers', as per Pass-book	298 12 6	
In hand of Assistant Secretary on Petty Cash Account	13 0 6	
In hand of Assistant Secretary on account of Turnor and Horrox Fund	0 19 6	
		312 12 6
Due on account of Subscriptions :—		
1 Contribution of 5 years' standing	10 10 0	
1 Contribution of 4 years' standing	8 8 0	
19 Contributions of 3 ,, ,, ...	119 14 0	
41 ,, 2 ,, ,, ...	172 4 0	
68 ,, 1 ,, ,, ...	142 16 0	
Other sums	2 11 0	
	456 3 0	
Less Contributions paid in advance	12 12 0	
		443 11 0
Due for Photographs and Publications supplied from Society's Rooms		9 9 0
Due from Wm. Wesley & Son for sales of Publications during the last quarter of 1916		14 9 2

£1,250 Metropolitan 3-per-cent. Stock.

£2,000 Swansea Corporation 3½-per-cent. Stock.

£3,500 East Indian Railway 3-per-cent. Debenture Stock.

£3,500 London and North-Western Railway 3-per-cent. Debenture Stock.

£4,000 Midland Railway 2½-per-cent. Debenture Stock.

£1,000 Lancashire and Yorkshire Railway 3-per-cent. Consolidated Preference Stock.

£2,400 Gas Light and Coke Co. 3-per-cent. Debenture Stock.

£2,000 Commercial Gas Co. 3-per cent. Debenture Stock.

£1,000 War Loan 4½-per-cent. Stock.

Astronomical and other Manuscripts, Books, Prints, Photographs, and Instruments.

Furniture, etc.

Stock of Publications and Photographs.

Five Gold Medals.

Celestial Photographs.

The following has been added to the list of Celestial Photographs reproduced by the Society for sale to the Fellows :—

R.A.S. Ref. No.

275. Hydrogen (H_α) Flocculi. Mount Wilson Solar Observatory.

A catalogue of photographs, Nos. 1 to 234, was published in the Annual Report for 1912 (*M.N.*, lxxii. p. 225). Supplementary lists were given in the Reports for 1915 and 1916.

The Award of the Gold Medal.

The Council have awarded the Society's Gold Medal to Mr. Walter Sydney Adams for his investigations in Stellar Spectroscopy, including the determination of Absolute Magnitudes. The President will lay before the Society the grounds upon which the award has been founded.

Publications of the Society.

During the past year vol. lxxvi. of the *Monthly Notices* has been published.

Obituary.

The Council regret that they have to record the loss by death of the following Fellows and Associates during the past year:—

Fellows:—Cleveland Abbe.
Walter Briscombe.
Arthur Brunel Chatwood.
John Francis Cole.
George Stickland Criswick.
William Ellis.
William Esson.
Benjamin Gregory.
William Hall.
Reinold John Jauget.
Thomas King.
Frederick William Levander.
Robert Cumming McFee.
John James Mellor.
John East Hunter Peyton.
David Powell Richards.
Thomas Davies Sewell.
Walter Spencer Stanhope.*
John Tebbutt.†
Samuel Veevers.
Arthur Mason Worthington.
Arthur Williams Wright.

Associates:—Johan Oskar Backlund.
Karl Schwarzschild.

Note.—Though not a Fellow of the Society at the time of his death, Professor Silvanus P. Thompson's resignation was received during the year, and it has been considered desirable that some account of his life and work should be given.

Professor Cleveland Abbe was born in New York City on 1838 December 3, and died at Chevy Chase, Md., on 1916 October 28, after a somewhat extended illness. He was a graduate of the College of the City of New York, receiving his A.B. in 1857 and A.M. in 1860. During this period the writings of William Ferrel, entitled *The Motions of Fluids and Solids on the Earth's Surface*, attracted his attention most especially, and seem to have helped to turn his attention more directly to the field in which he was

* Deceased in 1912, but not reported till 1916.
† Obituary deferred.

afterwards so eminent. It seems, however, that even earlier in his life he had been impressed with the faulty knowledge of weather conditions and the lack of scientific accuracy in many of the meteorological papers then published.

In 1860 he enlisted in the Union Army, but his near-sightedness was so great that he was shortly afterwards discharged as being totally unfitted for military duty from this defect. He then turned to astronomy, which indeed he had already studied, and worked under Dr. Gould at Cambridge, Mass., in the U.S. Coast Survey. Next he went to the Pulkovo Observatory, Russia, where he remained as a guest from 1864 to 1866. On his return to America he served as aid in the U.S. Naval Observatory during 1867–8, until he was appointed to the directorship of the Cincinnati Observatory in Ohio, where he remained until 1873.

These many useful years in the service of astronomy did not, however, turn him from his earlier interest in meteorology, and indeed his appointment at Cincinnati opened to him the opportunity for his greater service to the latter science. This he accomplished by establishing a private weather service from his observatory, in co-operation with the Western Union Telegraph Company. This brought at once national attention to the undertaking as it never had been before. Urged on by the success of this experiment, Congress passed an Act in 1870 authorising the creation of a weather service, and placing it under the Signal Service Branch of the War Department. Professor Abbe was naturally called to take a prominent part in the new bureau, and began his duties in 1871 as Professor of Meteorology and Senior Scientific Assistant to the Chief Signal Officer. This post he filled for forty-five years, finally being forced to resign from ill-health only a few months before his death.

During this period of his life he found time to take part in many other activities. Thus we find him lecturing on meteorology at George Washington University from 1886 to 1909, and also at Johns Hopkins University in 1896. He edited with great success *The Monthly Weather Review* from 1872 to 1909, bringing that journal to its present high standard of efficiency. He took part in the expedition sent out by the Government in the U.S. cruiser *Pensacola* to West Africa in 1889 to observe the total eclipse in December of that year. While at sea on this expedition he also made most valuable cloud observations. Indeed his interest in astronomy never grew dim, and during the last years of his life he spent much study upon the invention of an instrument for automatically photographing and recording the velocity of meteors. A report on this was read at the meeting of the American Astronomical Society in 1916 August, in which he described the perfected form of this instrument. His interest in the subject of meteors was particularly great, because he realised their immense importance in giving us almost our only direct information on the currents in our upper atmosphere, both through study of their trains and other phenomena. Perhaps the very latest scientific act of his life was

to approve of a report on the subject of meteors, drawn up by Dr. C. P. Olivier, and submitted to him for criticism and approval, only two weeks before his death. For many years he had been Chairman of the Meteor Committee of the American Astronomical Society.

Professor Abbe's influence upon the present status of meteorology in America is incalculable, and his contributions are far too numerous to begin even to mention. To write out the names of all the scientific societies at home and abroad of which he was a member would alone fill a full page. He was honoured both in Europe and America in nearly every way a scientist could be. Perhaps the honours he prized most came to him late in his life. These were the Symons Memorial Gold Medal, presented by the Royal Meteorological Society of Great Britain in 1912, and the Marcellus Hartley Medal, awarded in 1916 April by the National Academy of Sciences of the United States. This last medal was presented "for eminence in the application of science to public welfare."

Among his longer and best known scientific works are *Preliminary Studies in Storm and Weather Forecasting*, 1889; *The Mechanics of the Earth's Atmosphere*, vol. i. in 1891, and vol. ii. in 1909; and *Physical Basis of Long Range Forecasting* in 1902. Of more direct interest to astronomers would be several reports on total solar eclipses, not to mention his work contained in various observatory publications.

Professor Abbe was of a genial and sympathetic disposition, unobtrusive in his manner, and always willing and glad to help younger men forward by all means in his power. He had a remarkable memory and very comprehensive view, especially in his chosen fields, and a great linguistic ability. As was natural, occasional attacks upon the policies of the Weather Bureau partly fell upon him, but he bore these criticisms calmly, and these unworthy efforts always came to nothing. When at leisure he was most approachable and a very pleasant companion to anyone, old or young.

He was married twice, first in 1870 to Frances Martha Neal of Cincinnati, who died in 1908; secondly to Margaret Percival of St. Kitts, W.I., in 1909. One of his three sons, Cleveland Abbe, jun., has followed in his father's footsteps, and now occupies a very high position in the Weather Bureau as meteorologist and acting editor of *The Monthly Weather Review*.

Only a few of the chief points of interest have been touched upon in this totally inadequate sketch of Professor Abbe's career, but more complete accounts will appear in several American journals.

Professor Abbe was elected a Fellow of the Royal Astronomical Society on 1876 January 14.

[The Council are indebted for the above notice to Dr. C. P. Olivier, of the Leander McCormick Observatory, University of Virginia, U.S.A.]

Walter Briscombe was born at White Lea, in the parish of Batley, Yorkshire, on 1836 March 30. After a few years in business, at the age of twenty-four he entered the Wesleyan Ministry, his first appointment being to the Ebenezer Chapel, Sheffield. In 1863 he was transferred to Grimsby, and subsequently was appointed to numerous circuits in various parts of England, in all of which his work was highly esteemed. After thirty-eight years of active circuit life Mr. Briscombe retired to Grimsby, but he still continued to preach and to carry on religious work. He took part in a missionary service the day before his death. He was keenly interested in astronomy, and obtained a practical acquaintance with the subject by the use of a 19-inch reflector and a 6-inch refractor which were placed at his disposal by a friend. He quietly disseminated a knowledge of astronomy in the various districts in which he was stationed.

Mr. Briscombe was twice married, and leaves a widow, a daughter, and a son. He died at Grimsby on 1916 September 29.

He was elected a Fellow of the Society on 1906 April 11.

John Francis Cole was born at Wandsworth on 1824 July 5. At the age of fourteen, his mother being a Swiss, he was sent to Switzerland to continue his education.

Mr. Cole was with Messrs. Baring Bros., Bankers, as confidential clerk, for fifty years. When he retired, at the age of seventy-nine, his faithful services were recognised in a very practical form by the continuance of his salary in full. He was an accomplished linguist, and spoke French, German, and Norwegian fluently. For four years in succession, after his retirement, he visited his old college at Lausanne, and delivered an oration in French to the students who had taken their degrees. He had a genuine interest in astronomy, dating from the time when, as a young man, he made some astronomical observations in Norway. Only a few years ago, notwithstanding his great age, he gave a lecture on Kepler's Laws to the Literary Society at Sutton, Surrey, where he resided during half a century.

Mr. Cole died from acute pneumonia, after one day's illness, on 1916 January 16, being then in his ninety-second year. He was twice married, but had no children. His widow survives him.

He was elected a Fellow of the Society on 1859 February 11, and it may be of interest to note that there now remain only two Fellows of the Society who were elected prior to 1860.

George Stickland Criswick.—During the past year the Society has lost two of its older Fellows who were intimate friends and colleagues for many years on the staff of the Royal Observatory, Greenwich. The younger of these, Mr. G. S. Criswick, died in the first month of the year, and forms the subject of this note. A similar note relating to the elder, Mr. William Ellis, is to be found next in this series.

George Stickland Criswick was a descendant of a Dorset family

who formerly owned Langford Court in the Parish of Burrington. His mother belonged to the Stickland family of Somerset. He was born on 1836 January 31, and was educated at King's School, Sherborne, with which ancient foundation he remained in touch until the end of his life. His father died when he was fifteen years old, and a financial disaster to his family prevented him going to a university as was intended, but his mother was able to procure for her elder son George a nomination as computer in the Royal Observatory, and she herself removed to Greenwich with her family.

George Criswick joined the staff at Greenwich on 1852 August 25, and early in 1854, on Airy's recommendation, he was transferred to the Cambridge University Observatory, taking up the position of Junior Assistant to Challis on May 1 of that year. In the following October the well-known pendulum experiment at Harton Colliery took place, and for this Airy borrowed observers from various British observatories, Criswick being lent from Cambridge. His subsequent stay at the University Observatory was short, for in 1855 February the departure of Charles Todd for Adelaide caused a vacancy, and Criswick was offered, and accepted, the position of Junior Assistant at Greenwich. He entered on his new duties on 1855 March 26, and almost at once took his place among the four regular observers—it was the custom at Greenwich, as it is now, that four of the established staff should take turns at observing with the Transit-Circle and other principal instruments day by day—and he continued to so observe until the end of the year 1881, this twenty-six years of continuous work with the Transit-Circle being the longest period yet accomplished by any observer with that instrument. In 1862 he was chosen to accompany Mr. Dunkin to Valentia Island in the south-west of Ireland to make observations for the telegraphic determination of the longitude of Knightstown.

As to his work in the Observatory, besides observing, for some years he was associated with Mr. Ellis in the conduct of the transit reductions, and in the Time-Signal and chronometer work of the Observatory. Later on, at successive re-organisations, he was entrusted first with the reduction of the zenith distances, then with the care of the library and manuscripts, and when, in 1874, Mr. Ellis was transferred to the Magnetic and Meteorological Department, Criswick was made Superintendent of the Time Department, and so remained until the end of 1881, when he left off observing and became Superintendent of Computers, taking general charge of the preparation of the Greenwich volume. In 1890 the Astrographic Equatorial was installed at Greenwich, and this was put into his charge, the photographic and mechanical manipulation being both very much to his taste. He remained Superintendent of the Astrographic Department until his sixtieth birthday in 1896, when he retired from the Observatory service at his own desire.

The above is a categorical recital of Mr. Criswick's work, and it certainly may be said that he did all conscientiously and to the best

of his ability. He was supple of hand and quick in perception, and took care to perfect himself in qualities and dexterities which go to make the skilled and useful observer, circumstances which may not have been sufficiently appreciated.

Apart from his official work, Mr. Criswick had several other interests. He supplied the astronomical information to *Whitaker's Almanack* from its first volume in 1869 until that for 1916. He was a great Freemason, and took a very active interest in the affairs of that brotherhood. He was of sociable and amiable disposition, and popular among a circle of many friends. He married in 1877 Miss Elise Tudor Hassall of Mount Sorrell, Leicestershire, who survives him. They had no children.* Mr. Criswick died on 1916 January 26 within a few days of his eightieth birthday.

He was elected a Fellow of the Society on 1868 February 14.

H. P. H.

William Ellis, who died on 1916 December 11, was the son of Thomas Ellis, an assistant to John Pond, Astronomer Royal in the early part of last century. Thomas Ellis was a native of York engaged in a commercial occupation, but evidently had a liking for and some knowledge of astronomy, for in 1825, at the instigation of William Richardson, who was also a north-country man, and already a member of the staff of the Royal Observatory, he came to Greenwich to take up a similar position. On 1828 February 20 his elder son William was born, and at the age of thirteen, after education at local schools, William Ellis was attached to the temporary computing staff then employed on the reduction of the observations of the Moon made at Greenwich between 1750 and 1830 which Airy had organised after the completion of the similar reduction of the ancient planetary observations. When these special computations came to an end in 1848, Ellis, with some of the others, one of whom was Charles Todd, was transferred to the Astronomical Department of the Observatory. In 1852 Richard Carrington, who had been until then the observer at the Durham University Observatory under the Rev. T. Chevallier, resigned that office, and on the recommendation of Airy the position was offered to William Ellis, who went to Durham in 1852 March.

The observer at Durham at that time seems to have been free to choose his own line of work to a great extent, and Ellis continued the series of observations of position of small planets begun by Carrington, and of comets. His observations of Westphal's Comet at its first apparition in 1852 will be found in vol. xxxvii. of the *Astronomische Nachrichten*, where also some of his planetary observations are published. Whilst Ellis was at Durham his father died (1852 May 29), the vacancy at Greenwich being filled by the promotion of J. C. Henderson, who did not hold his office for long, but resigned in 1854 April. Charles Todd, who had been

* Henry Criswick, who is mentioned in the Introduction to Carrington's Sun-Spot volume as having helped in that work, was the younger brother of G. S. Criswick, and was for a time a computer at Greenwich.

transferred to the Cambridge University Observatory, was recalled to succeed Henderson in 1854 May. Another vacancy had occurred in the Greenwich permanent staff in 1853 April by the death of William Rogerson, who had been on Pond's staff, and W. Ellis returned to Greenwich to fill this in the following month, and at once took his place among the regular observers with the Transit-Circle and Altazimuth, the four being, when Todd left Greenwich, as he did shortly after, Henry, Dunkin, Ellis, Criswick. Henry* resigned and died in 1856, when W. T. Lynn joined the staff, and the four thus modified, with James Carpenter added, did the bulk of the routine work of the Observatory for nearly twenty years.

Todd left Greenwich in 1855, and his work, which had been the care of the newly introduced galvanic apparatus within the Observatory and the Time-Signals, was handed over to Ellis. When Henry resigned, the custody of the chronometers also passed into his hands, and thus what is now known as the Time Department was created. This remained in Ellis's charge until the end of the year 1874. During this period there was much extraneous work not in the immediate routine of the Royal Observatory that he was called upon to do, and even before that he had been with Mr. Dunkin one of the observers in the Harton Colliery pendulum experiment in the autumn of 1854. The galvanic determination of longitudes from Greenwich was work connected with his department, and in this way he took a share in the determination of the longitude of Edinburgh (1857–1858), Knightstown, Valentia (1862), and of Glasgow (1865). On these occasions Ellis made the arrangements for the signals and provided, with others, the error of the clock at Greenwich, but did not observe at the distant station. He helped similarly in the Trans-Atlantic longitudes made by American parties in 1866 and in 1873, and also in determining the longitude of Cairo in connection with the observation of the Transit of Venus in 1874. On this occasion he went to Porthcurno in Cornwall, the station of the Eastern Telegraph Company, to receive signals from Alexandria and Greenwich for comparison of the clocks at the two places.

At the end of the year 1874 Mr. James Glaisher having resigned the office of Superintendent of the Magnetic and Meteorological Department and left Greenwich, Ellis, at his own request, was transferred to that position, in which he earned considerable reputation. To estimate correctly the value of the contributions Ellis made to the science of earth magnetism and its connection with sun-spots, it is necessary to consider the history of the subject during the middle period of last century, which is briefly given in the following abstract from Mr. Ellis's writings:—

"It was said by Delambre that the observation of sun-spots was of little account, and that they were more curious than useful, but early in the nineteenth century (1826) Schwabe began his daily record of the solar surface, and

* This is Mr. John Henry Belville, whose name is known in connection with certain meteorological journals. He appears in the Observatory volumes as Mr. Henry.

in 1843 made his announcement of a probable decennial period. In 1841 certain observatories, of which the Greenwich Magnetic Observatory was one, were established in different parts of the world where observations of the elements of earth magnetism should be made for a period of three years. Interest was aroused in this work shortly after their establishment by the occurrence of a considerable magnetic disturbance which was recorded at Greenwich, and was found to have taken place at other observatories at distant places, beginning, as it would appear, at about the same absolute time. Work at these observatories was continued beyond the three years originally intended, and the results were put into the hands of General (Sir Edward) Sabine for discussion. In a paper communicated by him to the Royal Society in 1852, 'On the Periodical Laws discoverable in the Mean Effects of the Larger Magnetic Disturbances,' he remarked that Schwabe's observations of sun-spots showed variations similar in character to those that he had pointed out in the magnetic elements, but added, that although there was this remarkable effect, it was necessary to wait for further observations to see if it was confirmed. Lamont at Munich, Wolf at Zurich, Alfred Gautier, and others found similar results, but astronomers in general seemed to be not very interested in this matter, some indeed disbelieved it. In England only Balfour Stewart wrote on the subject, and his papers were for some reasons not convincing. Whilst in the Astronomical Department my attention had been drawn to the question as one deserving investigation, and when I took up the position of Superintendent of the Magnetic and Meteorological Department and looked daily at the photographic registers of the magnets, I found that in character they were quite different to those of the immediately preceding years, and looking farther back the question seemed to be no longer doubtful, and in course of time I made a graphical representation on a considerable scale of the variations of diurnal range of Declination and Horizontal Force, adding thereto the representation of the variation of sun-spots from the years 1841–1877. On showing this to Sir George Airy, he was charmed to find that the Greenwich observations for so long a period should in so definite a manner confirm the existence of relation between sun-spots and magnetism. The paper that I then prepared, entitled 'On the Relation between the Diurnal Range of Magnetic Declination and Horizontal Force as observed at the Royal Observatory, Greenwich, during the Years 1841–1877 and the Period of Solar Spot Frequency,' was presented by Airy to the Royal Society, and published in the *Philosophical Transactions*, 1880, part 2."

Mr. Ellis's remark as to the attitude of the astronomical world towards a possible connection between sun-spots and magnetism, or at any rate to Sabine's suggestion of a decennial period in the latter, is supported by remarks made by Airy in two papers on Terrestrial Magnetism presented by him to the Royal Society in 1863 and 1868 respectively. In the first he says, speaking of great magnetic disturbances: "There is no appearance of decennial cycles in their recurrence," and in the second, "If they point to any cycle at all, it is one of 6 or $6\frac{1}{2}$ years"; though, on the other hand, it is not to be denied that many persons must have had the possibility of such a connection in their minds, and that papers were written leading to this as a conclusion: but it seems that a definite relation between the phenomena of earth magnetism and sun-spots was not a household word in the world of science until after the publication of Mr. Ellis's Memoir of 1880. He extended the inquiry to include the period 1841–1896 in a paper in vol. lxii. of the *Proceedings of the Royal Society*, and in a third paper in the *Monthly Notices* for December 1899 the relation of magnetic disturbance to sun-spots was further considered.

A paper "On the Simultaneity of Magnetic Variations at Different Places on the Occasions of Magnetic Disturbance, etc." to the *Proceedings of the Royal Society* in 1892, is a valuable contribution to the subject.

The other branch of Mr. Ellis's department, Meteorology, also received much of his attention during the latter part of his life. He was elected a Fellow of the Meteorological Society in December 1875, served on the Council from 1878 to 1908, was elected President in January 1886, and held the office for two years. He contributed many papers to the Quarterly Journal of the Society, these being generally of the nature of tabulation and discussions of the observations made at Greenwich. On the occasion of an exhibition of barometers organised by the Society in the first year of his presidency he delivered an address on the history of the instrument, comprising a list of nearly two hundred known forms, which must have cost much research. He wrote much on minor points connected with the subject in Symons's *Meteorological Magazine.*

As to his contributions to the literature of our own Society, two Memoirs are to be found in the list under his name, one being an astronomical interpretation of the inscriptions on four old tablets discovered in Egypt, published in 1856. The other is a discussion, or collection, of results showing the periodic movement of the Greenwich Transit-Circle, and it is known that the extensive computations for the memoir in vol. xxviii., "On the Apparent Projection of Stars on the Moon's Disk in Occultations," published in Airy's name, was done by Ellis in his spare time at Airy's request. In the volumes of the Royal Society's list of papers there are in all about fifty entries to Ellis's name, which include those above specified, with others contributed to the *Monthly Notices*, the *Horological Journal*, *Nature*, and other publications, dealing chiefly with matters concerning Time and its determination and distribution, or Meteorology. Mr. Ellis retired from the service of the Royal Observatory at the end of the year 1893. He attained the age of sixty-five, when resignation is usually requested by the rules of the Government Service, earlier in that year, but was retained in order that he might complete a Greenwich publication that he had in hand, this being a compilation in tabular form of the observations of temperature made at Greenwich in the fifty years 1841–1890 that he had arranged. This collection of a mass of figures, and its freedom from error, was one of the things of which Ellis was proud. He was clever as a statistician and a computer, and in the early part of his life did extraneous work in the way of reducing the observations made by travellers for latitude and longitude. It fell to him in 1857 to supervise the reduction of Dr. Livingstone's observations as part of his observatory work, and later, at the request of the Geographical Society, the observations of Cameron, also made in African travels, and those of several others came into his hands. Towards the end of his life he often spoke with pleasure of the

confidence that Airy placed in him, and of his acquaintance with the leading men of his early days, Sheepshanks, De la Rue, and others, whom he felt honoured to have met on terms of friendship. Mr. Ellis was elected a Fellow of the Royal Society on 1893 June 1, soon after his paper "On the Simultaneity of Magnetic Variations, etc." He became a Fellow of our Society 1864 December 9, and was nominated an Honorary Member of the British Horological Institute in 1865. In 1873 he became a Member of the Institution of Electrical Engineers, and, as already said, a Fellow of the Royal Meteorological Society in 1875.

He was twice married, but had no children—on 1869 June 20 to Sarah Elizabeth Campion of Bellingham, Northumberland, who died in 1906, and secondly, on 1908 December 7, to a distant cousin, Margaret Anne Ellis of Settle, Yorkshire, who survives him. His younger brother died at sea in his youth, and his two sisters predeceased him. His portrait is to be found in the British Museum of Portraits—South Kensington Collection. Mr. Ellis died purely from the weakness of old age on 1916 December 11, being conscious and active in mind almost to the last.

H. P. H.

William Esson was born at Carnoustie, in Forfarshire, on 1838 May 17. He was educated at the Inverness Royal Academy and Cheltenham Grammar School. In 1855, before his seventeenth birthday, he matriculated at Oxford University on his election to a Bible Clerkship at St. John's College. In addition to all the possible honours in mathematics, he gained a First and a Second Class in the two Classical Honours Examination. In 1860 he gained a Fellowship at Merton College, and in 1897 he was appointed to the Savilian Chair of Geometry in succession to J. J. Sylvester.

He collaborated with Dr. A. V. Harcourt in investigations into the rate of chemical change, and for this work he gained the Fellowship of the Royal Society in 1869. After an interval of thirty years these researches were resumed, and a (third) paper on the subject appeared in the *Philosophical Transactions* in 1895. His other publications were neither numerous nor of great importance. He devoted his energies to lecturing and tuition as well as to administrative work, which grew more and more engrossing, and proved increasingly valuable to his College and to the University.

In 1875 June the Convocation of the University passed a statute establishing the University Observatory. Esson was elected a Visitor (at the same time with Bartholomew Price and Warren de la Rue), and at the first meeting of the Visitors he was elected their secretary. This office he held until his death, *i.e.* upwards of forty years.

He was elected a Fellow of the Society on 1863 February 13.

[The Council are indebted for the above notice to his friend Mr. H. T. Gerrans, M.A., Worcester College, Oxford.]

Benjamin Gregory was the son of a contractor, and was born at Hanley on 1839 December 2. Owing to family financial losses he had few educational advantages, but by strenuous personal efforts he became qualified at the age of seventeen years to take up an appointment as assistant master in a school at Wolverhampton. He afterwards assisted for some time in his father's business, and subsequently served as cashier and confidential clerk to a firm of ironfounders at Wolverhampton. In 1866 he entered the firm of Messrs. Engall & Co., Auctioneers and Surveyors, Cheltenham, and remained with this firm, first as accountant and surveyor, and then as partner, until his retirement a few years ago.

Mr. Gregory was an extremely industrious and studious man. All his spare time was devoted to study, and he acquired a considerable knowledge of ancient and modern languages, as well as of a variety of scientific subjects. Astronomy, however, was his favourite study, and he pursued the subject in a practical way with the aid of telescopes which he constructed himself. He gave numerous instructive lectures at the various churches and institutions in Cheltenham, covering a wide range of subjects, among which astronomy took a prominent place in recent years. As a local preacher he rendered valued service to the Wesleyan Methodist Church, of which he was a greatly esteemed member.

He died on 1916 October 20, after a week's illness, from pneumonia, leaving a widow, three sons, and four daughters.

He was elected a Fellow of the Society on 1913 January 10.

William Hall was born at Birtley Vicarage, North Tyne, in 1867. He entered Rossall School with a mathematical scholarship in 1881, and distinguished himself by obtaining Honours in History and French as well as in his own special subject. He became captain of the school, and twice took the gymnasium championship. Having won an open Mathematical Scholarship in 1886, he proceeded to King's College, Cambridge, where he was awarded the Abbot University Scholarship, and came out as twenty-second Wrangler in the Tripos.

Mr. Hall returned to Rossall as a master in 1890, remaining there for three years, and finding full scope for his many gifts. He was truly an all-round man, for, apart from his scholastic attainments, he was an accomplished musician, and was skilled in carpentry and other crafts.

Having meanwhile married and taken Holy Orders, Mr. Hall left Rossall in 1894 to take up an appointment as chaplain and naval instructor at the Royal Naval College. In the following year he was appointed in the same capacity to H.M.S. *Endymion*, and subsequently served in other ships during a period of about ten years. He appears to have been strongly impressed with the possibility of improving the practice of navigation, and he devoted himself to the task of reform with characteristic energy and thoroughness. His invention of a nautical slide rule in 1902 was

soon followed by his *Modern Navigation*, which, with his *Tables and Constants*, was adopted by the Admiralty for use in the Navy. He also revised and brought up to date *Inman's Nautical Tables*, in which were included many valuable aids to the rapid fixing of position. Shortly before his death he published a useful stereographic projection to facilitate the solution of problems met with in connection with night-marching and flying by the stars.

In 1905 Mr. Hall was recalled from the sea to the post of Chief Instructor at the Royal Naval College, Dartmouth, where he remained for five years. After a further two years afloat he was detached for service as Director of Studies at Geelong, and rendered important aid in the development of the Australian Navy. The leave to which he was so well entitled was sacrificed to the necessities of the war, and it was while serving on H.M.S. *Venerable* in the Mediterranean that he met with the immediate cause of his untimely death. An order for inoculation having been given, he insisted on taking his share of the discomforts, and, unfortunately, pyæmia set in. After several operations, and six weeks of suffering in hospital, he was sent home, but only survived his arrival by twenty-four hours. He died at the Royal Naval Hospital, Plymouth, on 1916 November 4.

He was elected a Fellow of the Society on 1910 January 14.

Reinold John Jauget was born at Libau, Russia, on 1870 August 18. He came to England about twenty years ago, and was naturalised in 1908. He followed the sea all his life, and at the time of his death was chief officer of H.M.S. *Ramazan*, which was torpedoed in the Mediterranean on 1915 September 19. The officers and crew had all escaped in the lifeboats, but were then fired upon, and the boat in which Captain Jauget had taken refuge was capsized, and he was never seen again.

Captain Jauget made his home in Sunderland, where he was married in 1911. He leaves a widow and a daughter, who was only eight months old when her father was drowned.

He was elected a Fellow of the Society on 1909 May 14.

Thomas King was born at Glasgow in 1858, and when two years old was taken out by his parents to New Zealand. He was educated at the Auckland Grammar School, and afterwards took up a business appointment at Wellington. Mr. King subsequently joined the staff of the observatory, under the directorship of Sir James Hector, and was responsible for the time service from 1887 to 1911, when he resigned. In 1903, in collaboration with Dr. Otto Klotz, he was occupied in a determination of the difference of longitude between Wellington and Doubtless Bay, as part of the programme for the determination of Trans-Pacific longitudes. He was the author of a paper "On New Zealand Mean Time, and on the Longitude of the Colonial Observatory, Wellington, with a Note on the Universal Time Question," published in the *Transactions of the New Zealand Institute*, vol. xxxv., 1902.

Mr. King, who was unmarried, died at Wellington on 1916 March 16.

He was elected a Fellow of the Society on 1910 June 10.

Frederick William Levander was born at Exmouth in the year 1839. Like his brother, Henry Charles Levander—also a Fellow of this Society—he adopted the scholastic profession, and was for many years one of the assistant classical masters at University College School, then located at Gower Street, London, W.C. In connection with his profession he wrote several educational books, amongst them *Test Questions on the Latin Language*, *Memorabilia Latina*, and *Solutions of London University Questions on Electricity and Magnetism.* He also brought out in conjunction with a former Warden of the Standards a series of models for teaching weights and measures.

He early manifested a keen interest in astronomy, and in 1860 published some observations of the crêpe ring of Saturn and of markings on the surface of Mars, made with a telescope of only $1\frac{1}{2}$ inches aperture. In 1871 he brought out a design for an equatorial mounting at a moderate price suitable for a refractor of 3 or 4 inches aperture, and seven years later a variable diaphragm for use in the observation of the Sun and stars.

His most important services to astronomy were, however, rendered rather in the field of literature than in that of observation. He compiled general indexes to the *Astronomical Register*, vols. i.–xx.; to the *Journal of the British Astronomical Association*, vols. i.–xviii.; and to the *Monthly Notices* of this Society, vols. lii.–lxx.

But it was the British Astronomical Association which was most deeply indebted to him. He was an original member of the Association, and became Librarian in 1895, to which, in 1900, he added the position of Editor of the *Journals* and *Memoirs.* To the *Journal* he contributed a great number of unsigned notes and reviews. He resigned the post of Librarian in 1906 on his election to the presidential chair of the Association, but he continued to fill that post until his death.

He was a prominent Freemason, being member of the Quatuor Coronati Lodge, for which he wrote several papers of an antiquarian character. Of this lodge he was Master at the time of his death.

Mr. Levander died at his residence, 30 North Villas, Camden Square, N.W., on 1916 December 20, after a very short illness, aged seventy-seven. He was interred at the Hampstead Cemetery, Fortune Green, on December 23.

His principal communication to this Society was a Discussion of the Colours of 4984 stars as described by various observers, with the special purpose of reducing such descriptions to a uniform scale. The paper was read at the meeting of 1889 November.

He was elected a Fellow of this Society on 1871 March 10.

E. W. M.

Robert Cumming McFee was born at Saltcoats in 1847, and was educated at the local academy. Adopting the sea as his profession, he served his apprenticeship in the *City of Paris*; after obtaining his master's certificate he joined the Anchor Line, and was soon promoted to the *Sidonia* as master. After three years' service he was appointed assistant marine superintendent, and in course of time became marine superintendent, which appointment he held up to the time of his death. In the Royal Naval Reserve he attained the rank of Commander.

Captain McFee took a great interest in astronomical studies. He was a talented writer, and was the author of many poems and articles, notably *Random Rhymes* and *Norman*. He was also a clever composer, and published many songs.

He died at his home in Glasgow on 1915 December 6, and is survived by three sons and four daughters, his wife having died in 1914.

He was elected a Fellow of the Society on 1912 January 12.

John James Mellor, who died on 1916 January 12, was born at Oldham on 1830 August 12. He was educated by private tutors and at private schools, and entered upon a business career. For the greater part of his life he was connected with the cotton-spinning and manufacturing industries, and was also interested in the administration of railways. He was chairman of J. & J. J. Mellor, Ltd., Bury, and of the Brook Mills Co., Ltd., Heywood. He was also for some time a director of the South-Eastern Railway and of the Metropolitan Railway. For twenty-seven years he was an officer of Volunteers, and retired from that service as Hon. Colonel 1st Volunteer Battalion Lancashire Fusiliers.

Colonel Mellor represented the Radcliffe-cum-Farnworth division of Lancashire in the House of Commons as a Conservative during the years 1895–1900.

He took great interest in engineering and other scientific pursuits. He was a Fellow of our Society for nearly sixty years, having been elected on 1859 March 11.

J. E. Hunter Peyton was born at Wakehurst, Sussex, on 1841 March 28. He was the eldest son of J. Wakehurst Peyton, Esq., 2nd Life Guards, of Wakehurst, his mother being the eldest daughter of Sir East Clayton East, Bart., of Hall Place, Sussex. His parents having died while he was still a child, his early days were chiefly spent at Hall Place. He attended a school at Rottingdean, and passed into Sandhurst in 1855. Two years later he obtained a commission and was appointed to the 60th Rifles. In 1858 he sailed for India, arriving at Madras after a voyage lasting 136 days. He was promoted to a lieutenancy in 1860, and returned to England in the year following. After service at Aldershot and the Tower of London, he retired from the army in 1863 on account of ill-health.

Having disposed of Wakehurst in 1870, Mr. Peyton settled at

St. Leonards and took a great interest in the local Philosophical Society, of which he was at one time President. He gave several lectures on astronomy and other scientific subjects, and on his experiences with the British Association in Canada. He also gave several papers on the water supply of Hastings, as determined by the local geological conditions. He had joined the Geological Society in 1871.

Mr. Peyton was married in 1866 to Sophia Henrietta, eldest daughter of the late Frederic Henry Lindsay, of the Commander-in-Chief's Office, Horse Guards. He had two sons and two daughters, of whom the latter survive him. He died on 1916 January 13.

He was elected a Fellow of the Society on 1870 January 14.

Thomas Davies Sewell was born in London on 1832 September 21, his father being Swordbearer of the City. He received his early education at the City of London School, and when thirteen years of age he entered the Chamberlain's department at the Guildhall. During fifty-six years, to his retirement in 1901, he rendered faithful service to the City Corporation, and became one of its best-known officials.

Colonel Sewell took a very active interest in military affairs. He was the first Volunteer to be enlisted in the London Rifle Brigade, in 1859, and was presented with a sword of honour in 1864, when he had attained the rank of captain. He joined the Royal London Militia as a lieutenant in 1866, and remained in association with this branch of the service until 1885, when he left as major and hon. lieutenant-colonel. After further military service he retired in 1892, but as senior proprietor of the *Broad Arrow* he maintained an interest in military matters to the end of his life.

Colonel Sewell was also closely associated with the work of various Livery Companies of the City of London, and rendered valuable services in the resuscitation of some of the minor Companies. His work in connection with the Spectacle Makers' Company will be of long-enduring value. As Clerk to this Company, Colonel Sewell helped to place on a firm basis the present scheme of examinations and awards of diplomas by which the qualifications of opticians to make and adjust spectacles are guaranteed and the confidence of the public secured.

Colonel Sewell died after a very brief illness on 1916 April 13, leaving a son and a daughter. Another son, Major S. D. Sewell, was killed in France in the early part of the year whilst serving with the Third London Field Company, Royal Engineers.

He was elected a Fellow of the Society on 1899 March 10.

Colonel Sir Walter Spencer Stanhope was born on 1827 December 21. He was the son of John Spencer Stanhope, of Cannon Hall, Barnsley, and Lady Elizabeth Wilhelmina, third daughter of the first Earl of Leicester. He was educated at Eton

and at Christ Church, Oxford. From 1872 to 1880 he was Member of Parliament for the Southern Division of the West Riding of Yorkshire. He was made a K.C.B. in 1904. In 1856 he married Elizabeth Julia, daughter of Sir J. J. Buxton, Bart.; she died in 1880, leaving three sons and three daughters. He died in 1912, but his death was not reported to the Society until 1916. He was one of the oldest Fellows of the Society, having been elected on 1857 February 13.

Silvanus Phillips Thompson was born at York on 1851 June 19. He was the son of Silvanus Thompson, who for many years was a schoolmaster at Bootham, York, where his son Silvanus received his early education. His father was a botanist, and from this influence were sown the seeds for scientific study which the son was to develop in so eminent a degree in after life. In 1867 he decided to train himself for the teaching profession, and for this purpose entered the Flounders Institute at Ackworth, Pontefract. Soon after that he matriculated at the London University, and in 1869 took his B.A. degree. Upon this he became junior master at Bootham, and from 1870 to 1875 was science master. In the latter year he gained a scholarship at the Royal School of Mines, and proceeded to London to pursue his studies there under Huxley, Guthrie, and Frankland. In the same year he took the B.Sc. degree, being bracketed first in the honours section. In 1876 he went to Heidelberg, where he learnt German and attended lectures by Bunsen and Quincke. In 1878 he took his D.Sc. degree, and was appointed Professor of Experimental Physics at University College, Bristol, a position he occupied for many years. On the establishment of the City and Guilds of London Technical College at Finsbury in 1885 Silvanus Thompson was appointed Principal, and resigning his professorship at Bristol, he came to London to take up his duties at Finsbury, where he became Professor of Applied Physics and Electrical Engineering, appointments which he held for thirty years until the day of his death.

Professor Silvanus Thompson's scientific life was devoted mainly to optics and the comprehensive subject of electrical engineering, and the enumeration of his researches on these subjects would form a very lengthy list. Besides numerous contributions to the *Philosophical Magazine*, the Royal Society and other institutions, he published many books of great value and interest. His first book, *Elementary Lessons in Electricity and Magnetism*, published in 1881, has run through many editions, and its high value can be estimated from its having been translated into French, German, Italian, Polish, and Japanese, in addition to a circulation in this country of over 100,000 copies. Professor Thompson was a high authority on electrical engineering, and his Cantor Lectures in 1883 "were a revelation to the engineering world as to the construction, theory, and mode of working of dynamo-electric machinery. This was about the time that the boom in electric companies set in, and he was constantly consulted

by financiers and others as to the value of the machines and processes which were being offered to the public." At this time he produced his manual on *Dynamo-Electric Machinery*, which has gone through eight editions, and has been translated into French and German. Later on he published his important work on *Polyphase Electric Currents and Alternate-Current Motors*, in which the subject of polyphase motors, transformers, and their application for factories and railways is treated with great fullness, and which has become a recognised text-book. He also published works on *The Electro-Magnet and Electro-Magnetic Mechanism*; on *The Dynamo-Electric Machine*; *Design of Dynamos*; *Electrical Tables and Memoranda*; also a translation from the Italian of Pacinotti's treatise on *The Electric Magnetic Machine*. In 1890 he again delivered the Cantor Lectures on the Electro-magnet, which embodied the results of six years' work. In 1901 he delivered the Boyle Lecture on "Magnetism in Growth," and in 1906 the Howard Lectures on "High Speed Electric Machinery," and in recent years contributed numerous lectures and papers on electricity and magnetism.

The eminent services which Professor Silvanus Thompson thus rendered to electrical engineering were recognised in 1899 by his election as President of the Institution of Electrical Engineers.

On the occasion of the three-hundredth anniversary of the death of William Gilbert of Colchester in 1903, Professor Thompson published a translation from the Latin of the chapter "On the Attraction of Amber, or more truly, on the Attracting of Bodies to Amber," from Gilbert's work *Tractatus, sive physiologia nova de Magnete*. He also published a translation of a letter of Peregrinus on the Magnet written in the thirteenth century.

To optics Professor Thompson also made many useful contributions. His Christmas Lectures at the Royal Institution in 1896 "Light Visible and Invisible" form an admirable elementary text-book.

Besides various lectures and papers on optics, he published a translation of Lummer's treatise on *Photographic Optics*, and also a very useful work on *Optical Tables and Data*. In 1912 he also translated from the French Huyghens's treatise on *Light*. In this connection he rendered important services to the Spectacle Makers' Company in conducting the examinations in optics for obtaining the diploma of that Company. This was productive of great advantage to the public in securing the efficient qualification of opticians in dealing with defective sight.

In other directions Professor Thompson's versatility was shown by a treatise on *Harmonic Analysis reduced to Simplicity*, by translations from Italian, and by some communications on rare works to "The Sette of Odd Volumes." As an artist he produced many clever water-colour drawings.

In his writings and lectures Professor Thompson displayed a power of very lucid exposition, with a command of excellent language and well-balanced sentences. This accomplishment enabled him

to produce a lengthy and masterly account, in two volumes, of the life and career of that most distinguished philosopher, Lord Kelvin. He also contributed a biography of Lord Kelvin to the *Dictionary of National Biography*. In 1895 he published a book on the *Life and Work of Faraday*.

In his writings and lectures Professor Thompson devoted much consideration to the reform of education, and he enunciated his policy in the following principles:—

1. To remodel all education in all branches, in order to remove the disadvantages which arise from men devoid of any idea of scientific method growing up into civil and industrial life.

2. To reconstruct the universities as centres of earnest work, from which idlers and triflers are rigidly excluded.

3. To ensure that university degrees shall be a mark of thorough training under competent teachers, and not mere attestations of cleverness in passing examinations.

4. To associate in close and living alliance the industrial enterprise and the scientific laboratory, industry helping science, equipping its laboratories, and ensuring that they are directed by men of scientific worth and experience.

Professor Silvanus Thompson was distinctly a highly educated man, proficient in several languages, with developed tastes in many directions, and a wide comprehensive knowledge of the special branches of science to which he devoted himself. As a teacher he had the faculty of attracting large crowds to his lectures, which it is said "were always pure joy and marvels of lucidity"; and, what is important, his experiments were almost invariably successful. His influence at Finsbury College was of immense value to the students, and the loss of so rare and able a teacher is profoundly regretted.

Professor Thompson received many distinctions. He was elected a Fellow of the Royal Society in 1891; he was a member of the Royal Academy of Sciences of Stockholm, of the Academy of Sciences of Bologna, of the American Philosophical Society; LL.D. of Birmingham, D.Sc. of Bristol Universities, and M.D. of the University of Königsberg. He was Past-President of the Institution of Electrical Engineers, of the Physical Society, of the Institution of Junior Engineers, of the Optical Society, of the Illuminating Engineers Society, and of "The Sette of Odd Volumes."

"The parents of Professor Silvanus Thompson were members of the Society of Friends, and he adhered to that body all his life. He exhibited many of the virtues which have long distinguished the Society of Friends, and his memory will be cherished by many whom he assisted in an unostentatious fashion when they were in difficulties."

After a short illness Professor Thompson died on 1916 June 12, leaving a widow and four daughters.

He was elected a Fellow of this Society 1875 May 14, and resigned February 1916. E. B. K.

Samuel Veevers was a well-known Liverpool cotton merchant. He started business on his own account in 1880, and throughout his life was held in high respect and esteem by his fellow-members of the Liverpool Cotton Association. Mr. Veevers devoted much of his leisure time to the study of astronomy, and wrote numerous articles on the subject for the local press. He died at his residence at Bootle, after a prolonged illness, on 1916 February 11, leaving a widow. He was sixty-two years of age.

He was elected a Fellow of the Society on 1907 February 8.

Arthur Mason Worthington was born at Manchester in 1852, and was educated at Rugby and at Trinity College, Oxford. After further work at Owens College, Manchester, and in the laboratory of Helmholtz at Berlin, he became headmaster of the Salt Schools, Shipley (1877–79), and went to Clifton College as an assistant master in 1880, remaining there until 1885. In 1887 he was appointed headmaster and professor of physics at H.M. Dockyard School at Portsmouth, and in the following year, when the school for naval engineers was transferred to the Royal Naval Engineering College at Keyham, Devonport, he went with it in the same position. Here he remained for twenty years, and was then transferred, as professor of physics, to the Royal Naval College at Greenwich. On account of ill-health, he retired in 1911.

Worthington's educational work was carried on with marked success throughout. He was a very able lecturer, and was especially successful in devising experiments with simple apparatus for the illustration of lectures and for purposes of instruction in the laboratory. He was a pioneer in the introduction of practical physics into schools, and his successful work at Clifton marks a definite epoch in the history of scientific education. While there, also, he did much to encourage interest in astronomy, and instructed a number of boys in the use of a 6-inch refractor erected by him in an observatory close to the College. His popular lectures on scientific subjects were always greatly appreciated, and it is recorded that in a lecture on astronomy in the prison at Princetown he succeeded in holding the attention of 1000 convicts from beginning to end.

Of the original investigations carried on by Worthington, his work on the stretching of liquids, and on splashes, is probably most widely known. His long series of observations of the latter phenomena are summarised in his well-known book, entitled *The Splash of a Drop*. He was also the author of works on *Physical Laboratory Practice* and the *Dynamics of Rotation*.

He was elected to the Fellowship of the Royal Society in 1893, and received the C.B. in 1902.

He died at Oxford, after a short illness, on 1916 December 5, leaving a widow, a son, and a daughter.

He was elected a Fellow of the Society on 1877 February 9.

Arthur Williams Wright was a descendant of Samuel Wright, who settled in Springfield, Mass., in 1639. He was born at Lebanon, Conn., on 1836 September 8, where his father, Jesse Wright, was at one time a member of the Connecticut House of Representatives. His whole life was practically identified with Yale University. His career as an undergraduate at Yale College was a distinguished one, the studies of his predilection being Latin, mathematics, and astronomy. He was also a very capable musician, both as a performer and as a critic.

After graduating in 1859 he continued his studies at Yale, specialising in science and mathematics, and in 1861 attained the degree of Ph.D., the first recipient of the degree in an American university.

For some years following he taught Latin and natural philosophy at Yale as a tutor. During this period he also studied law, and was admitted to the bar in 1868, though he never practised. In the years 1868–69 he studied at Berlin and Heidelberg, and from 1869 to 1872 held the professorship of physics and chemistry at Williams College. In 1872 he returned to Yale, and was appointed to the professorship of molecular physics and chemistry. This office he held until 1887, when he was relieved of the chemical professorship, and became the first professor of experimental physics.

To his initiative was due the construction of the first Sloane Laboratory of Yale College, the first laboratory for the study of experimental physics erected in America. In this laboratory too worked that distinguished physicist, Professor J. Willard Gibbs.

Not only did Professor Wright build a physical laboratory, but he for over thirty years conducted many important investigations, chiefly on electrical discharges. He was the first to experiment with X-rays in America, and to obtain photographs by their agency. His published papers appeared almost entirely in the *American Journal of Science* between the years 1870 and 1901. In particular, in the year 1877 Professor Wright published two important papers on the deposition of metallic films by the cathode discharge in vacuum tubes, and on a new process for the electrical deposition of metals, and for constructing metal-covered glass specula.

Professor Wright's astronomical work was chiefly concerned with polariscopic observations of the zodaical light, of Coggia's comet of 1874, and of comets *b* and *e* 1881, in which he successfully employed a polariscope of his own design. He also took part in an expedition in Colorado to observe the total solar eclipse of 1878 July 29, and observed the polarisation of the solar corona. As early as the year 1874 he had studied and determined the spectrum of the zodiacal light.

But probably the most important astronomical research which he undertook was his elaborate investigation of the gases of meteorites, contained in a series of five papers, published in the *American Journal of Science* during the years 1875 and 1876,

which form the foundation of our knowledge of these substances. Professor Wright studied the gases given off from six stone and five iron meteorites, for the most part from the collection at Yale University. His chief conclusions may be thus summarised. In the first place, no one of the irons which he analysed gave any spectroscopic evidence of unknown elements. Next he determined the percentage of the various gases H, CO_2, CO, N_2, and CH_4 in the meteorites, and showed that CO_2 is more abundant in the stones, and H and CO in the irons. The relative abundance of oxides of carbon in meteorites was one salient result of this research, and Professor Wright did not fail to point out the bearing of these observations on the spectra of comets as tending to support their meteoritic origin.

Professor Wright's activities were not confined to the experimental work carried on in his laboratory. He served on several Government Commissions, and from 1881 to 1886 as an adviser to the Signal Service. He also acted as one of the revisers of the editions of Webster's Dictionary, published in 1864 and 1890, particularly in the matter of scientific and technical definitions in physics and chemistry.

Professor Wright was elected a member of the American National Academy of Sciences in 1881; he was also a member of the American Philosophical Society; of the Connecticut Academy of Sciences; the American Metrological Society; the New York Academy of Sciences, and other scientific societies.

His death took place at his home in New Haven, Connecticut, on 1915 December 19. He was married in New Haven, 1875 October 6, to Miss Susan Forbes, eldest daughter of Professor Benjamin Silliman, jun., who predeceased him on 1890 February 17. Two daughters and one son survive him.

He was elected a Fellow of the Royal Astronomical Society on 1879 January 10. A. L. C.

Johan Oskar Backlund (Oskar Andrejewitsch) was born 1846 April 28 in the Parish of Långhem, in Wermland, Sweden. At the age of twenty he was a student of mathematics and astronomy at Upsala. In 1873 he became assistant to Gyldén at the Observatory of Stockholm, writing there his dissertation on the planet Iphigenia. In 1875 he became Docent in Upsala, and from thence went as observer, in 1876, to the Observatory at Yuryev (Dorpat). In 1879 he was invited by O. Struve to become assistant astronomer at Pulkovo. His theoretical work, especially in regard to Encke's Comet, led to his election as member of the Academy of Sciences of Petrograd in 1883. About this time he became a naturalised Russian subject. From 1887 to 1895 he was resident in Petrograd. In 1895 he succeeded M. Bredikhine as Director of the Observatory of Pulkovo, where he remained twenty-one years, winning the devotion and affection of his colleagues and assistants by his genial and friendly ways. He died suddenly on 1916 August 29.

His scientific activity falls into three parts: (1) the direction of the work of the observatories under his charge; (2) participation in international scientific projects; (3) the theory and the study of the movement of the bodies of our system, the comets, particularly Encke's, the small planets, and the earth. Under his care the observatory at Pulkovo has much increased, in personnel, in instruments, and in output. But the climate of this observatory being unfavourable for observation, he used his great personal influence to secure the foundation of two others in South Russia, one at Nicolaieff (seventy-five miles N.E. from Odessa), where, it is said, 300 days of the year may be good observing days, and another at Simeïs, in the Crimea. In the last few years the Russian Government had sanctioned his expenditure of large sums for the purpose of procuring astrophysical equipment for the new observatories. And his recent letters to English correspondents contained frequently reiterated expressions of the pleasure with which he looked forward to visits to England in connection with his engagements with Sir Howard Grubb.

Dr. Backlund represented Russia in the international commissions for geodesy, seismology, astrography, solar physics, etc. His death followed very closely on that of his friend Prince Boris Galitzine, who died on 1916 May 17, and thus observational science in Russia suffers a doubly severe blow in critical times. His unstinted activity in international scientific undertakings brought him into intimate friendly relations with colleagues in many lands. He was specially well known in this country, and was a warmly welcomed guest wherever he went. His tall, active form and his soldierly bearing made him a notable figure in any public gathering. He spoke English, French, German, Russian fluently, though he always maintained that in spite of his being able to speak many languages he was master of none, not even of his own; and the special turn that he gave to his English seemed only to emphasize the kindly geniality of his mind. Among his recent visits to England, we may recall his presence at the Cambridge Meeting of the British Association in 1904. He came again in the following year to travel to South Africa for the Meeting of the British Association, and for a visit to his friend Sir David Gill. In 1909 he made a special journey to England to receive the Gold Medal of the Society, and in September of the same year he came again for the Meeting of the International Geodetic Conference in London and Cambridge, under the presidency of his friend Sir George Darwin. Those who had the pleasure of visiting Pulkovo record not only the genial hospitality with which they were received and entertained by Dr. and Madam Backlund, but also the vivid interest with which he showed the treasures of the famous observatory.

His theoretical work appears to have been for the most part published in the Memoirs and in the Bulletin of the Academy of Petrograd (here referred to as *Petr. Mem.* and *Petr. Bull.* respectively), with occasional papers in the *Astr. Nachrichten* and

elsewhere. He supervised the publication of the second volume of Gyldén's *Traité analytique des orbites absolues des huit planètes principales* (1908), of which only 192 of the 323 quarto pages were in the press when Gyldén died, though Backlund insists that the enormous calculations these contained are for the most part due to MM. Sundman and von Zeipel. Evidently he was throughout keenly interested in the fundamental problem of how to deal in a general theoretical way with the terms of long period, and his work in this regard, as coming from a practical astronomer, appears to have a high interest. He published papers on the development of the disturbing function: *Petr. Bull.*, xxiv., 1878, "Développement en séries convergentes des puissances négatives impairs des quarrées de la fonction $1 - 2\eta U + \eta^2$," and a paper with nearly the same title in *Petr. Bull.*, v., 1896. Also, *Astr. Nachr.*, 3223 (1894), "Sur l'application d'une formule de Tchebycheff au développement de la fonction perturbatrice," and *Petr. Mem.*, xxxii., 1884, "Zur Entwickelung der Störungsfunction." But particularly should be mentioned such papers as *Petr. Bull.*, xxvii., 1881, "Développement des perturbations absolues d'une comète"; *Petr. Bull.*, xxxi., 1887, "Report on Harzer's paper, 'Recherches sur un cas spécial des problème des trois corps'"; *Astr. Nachr.*, 2920–2921, 1889, "Ueber die kleinen Divisoren bei den elementären Gliedern in der Theorie der Planetenbewegungen"; then his two important papers, *Petr. Mem.*, xxxviii., 1892, and vi., 1898, on the planets of the Hecuba type, in connection with which may be mentioned his papers, *Petr. Bull.*, vi., 1897, "Ueber die Integration der Differentialgleichung der Radiusvector einer gewissen Gruppe der kleinen Planeten"; *Petr. Bull.*, xvi., 1902, "Ueber die Bestimmung der Glieder langer Perioden mit besonderer Rücksicht auf die kleinen Planeten der Hecuba Gruppe," and also, for convenience, "Ueber eine horistische Differentialgleichung Gyldén's," *Petr. Bull.*, xvi., 1902. Then also, with the same underlying problem, his paper, *Petr. Bull.*, viii., 1898, on the possible librations of the satellites of Saturn, and the discussion of the long-period terms in his paper, *Petr. Bull.*, xii., 1900, "Zur Theorie der Präcession und Nutation."

But though such papers are important, the work that took the eye, and had its price, is naturally the enormous task of securing the recalculation of the planetary perturbations of Encke's Comet, with the connected revision of the estimate of the mass of Mercury, which he finally places at $(9{,}700{,}000)^{-1}$. His final standard publications in regard to this matter are the "Calculs et recherches sur la comète d'Encke," *Petr. Mem.*, xxxviii.–vi., 1891–1898, six parts in folio, and "La Comète d'Encke," i.–iii., *Petr. Mem.*, xxiii., xxiv., xxx., 1909–1912. Of these he published summaries, *Bull. Astron.*, xi., Paris, 1894, "Sur la masse de la planète Mercure et sur l'accéleration du movement moyen de la comète d'Encke," and *Monthly Notices*, lxx., 1910, "Encke's Comet 1895–1908." This latter is subsequent to the valuable and interesting address given by Professor Newall on the occasion of the presentation

of the Society's medal to Backlund, *Monthly Notices*, lxix., 1909. The reader is referred to these two papers in the *Monthly Notices*. Writing the mean daily sidereal motion of the comet in the form $n = n_0 + n_1\tau$, where n_0 is between 1070″ and 1080″ and τ is the time in days divided by 1200 (the period of the comet approximately), Backlund concluded that from 1819 to 1858 n_1 was 0″·1; in 1861, 1865, and 1868 n_1 had diminished to 0″·08; from 1871 to 1895 further to $n_1 = 0''{\cdot}062$, and that there were comparatively sudden changes in n_1 in 1858, 1868, 1895, and probably also in 1904. In regard to the mass of Mercury, it may be remarked that von Asten, in his two papers, *Petr. Mem.*, viii., 1872, "Berechnung eines wichtigen Theiles der absoluten Jupiterstörungen des Encke'schen Cometen," and *Petr. Mem.*, xxvi., 1878, "Resultate aus den Erscheinungen 1819–1875," beginning with the estimate $m_0(\☿) = (4{,}360{,}000)^{-1}$ (p. 5 of the second memoir), finally concludes (p. 109) that $m_0 = (7{,}636{,}440 \pm 195{,}907)^{-1}$. Backlund, whose earlier papers* on Encke's Comet ("Untersuchung über die Bewegung des Encke'schen Cometen 1871–1881," *Petr. Mem.*, xxxii., 1884, "Comet Encke 1871–1885," *Petr. Bull.*, xxx., 1886, and "Comet Encke 1865–1885," *Petr. Mem.*, xxxiv., 1886) are intimately bound up with von Asten's papers, remarks (*Petr. Mem.*, xli., 1893) that for the period 1848–1865 he has recalculated the perturbations due to Venus, Earth, Mars, Jupiter, and Saturn, taking intervals of five, ten, and twenty days, the osculating elements being changed at least once in each revolution, and that then the terms of second order arising from the action of Jupiter become very sensible, and that this explains a divergence from von Asten's results, who had neglected these terms save for 1855–1858 and 1865–1868, and then used an incorrect formula. But Backlund pays a high compliment to von Asten's accuracy of computation, many of whose results are embodied in his own.

Some brief remarks seem to be called for as to the methods employed in these computations. Von Asten's earlier paper of 1872, referred to above, sets out with the intention of combining Gyldén's method for a general analytical theory with Hansen's suggestion of partial anomalies made in his Paris Prize Essay on Comets (1856). In his second paper of 1878, von Asten appears to abandon the possibility as being too laborious. Backlund, however, in his paper, "Zur Theorie des Encke'schen Cometen," *Petr. Mem.*, xxviii., 1881, returns to the attempt to formulate an analytical theory by improvement of von Asten's (see also *Petr. Mem.*, xxxii., 1884, "Zur Entwickelung der Störungsfunction"); and Part 6 of his standard papers (*Petr. Mem.*, vi., 1898), "Perturbations produites par la Terre, Vénus et Mercure dans la partie supérieure de l'orbite de la comète," is preceded by an exposition of the application of Hansen's Paris Essay to the problem in hand.

In the numerical work Backlund had sometimes used the Hansen formulæ for the computation of the mean anomaly, the

* Still earlier papers are, one written with Bonsdorff on the perturbations of Encke's Comet, Stockholm, 1876, and another published at Petrograd, 1881.

logarithm of the radius vector, and the latitude in the orbit, and sometimes the older method, known as that of variation of the constants, in which the perturbations of the six elliptic elements are directly computed. Thus for the movement of the comet in the *lower* part of its orbit, in Part 5 of his standard papers, *Petr. Mem.*, xlii., 1894, he has used the method of variation of constants for 1819–1848, but for 1848–1871, 1871–1891 he has used Hansen's method (*cf.* also p. 6 of the paper, "Comet Encke 1865–1885," *Petr. Mem.*, xxxiv., 1886). In using Hansen's method he refers to the scheme of formulæ given by Powalky, *Astr. Nachr.*, 1438 (1863), which, however, he corrects in some points. He gives a *résumé* of the actual formulæ used, in Part 2 of his standard papers, *Petr. Mem.*, xli.* The formula for the mean anomaly

$$M = M_0 + n_0 t + k\tau^2 + m_1 \cos 2u + \ldots$$

where $\tau = t/1200$, $k = 6oon_1$, $m_1 = -3''{\cdot}66$, is deduced in Backlund's "Untersuchungen . . .", *Petr. Mem.*, xxxii., 1884, from the hypothesis of a resisting medium, by the introduction, after Gyldén, of an elliptic integral

$$u = \frac{\pi}{2K}\int_0^{\frac{1}{2}f} \frac{d\theta}{(1-k^2\sin^2\theta)^{\frac{1}{2}}},$$

with the help of the formulæ of elliptic functions originally due to Jacobi and Abel.

Attempt has been made in this note to give materials from which a competent account of Backlund's work in the theory of orbits could be begun. It may suffice to show that this would involve a wide and interesting study of an important phase in the history of theoretical astronomy. That he bore with such distinction his part in this development would be alone an enduring title to remembrance, apart from his contributions, many of them unmentioned here, to practical astronomy.

Dr. Backlund became an Associate of the Royal Astronomical Society 1898 December 9, and a Foreign Member of the Royal Society in 1911. H. F. B.

Karl Schwarzschild was born at Frankfort 1873 October 9. He was educated successively at the public school at Frankfort and at Strasburg and Munich universities. He gave early evidence of remarkable mathematical ability, and when barely sixteen contributed two excellent papers to the *Astronomische Nachrichten* on the problem of determining an orbit from three observations. At Munich he came under the inspiration of Seeliger's teaching, which had a very lasting influence on his mind. His first astronomical post was at the Von Kuffner Observatory, Vienna, where he was assistant from 1896 to 1899.

* *Cf.* Encke, *Astr. Nachr.*, 791–2 (1852); *Astr. Nachr.*, 814 (1852); Bond, *Mem. Amer. Acad.*, iv., May, 1849; Hansen, *Astr. Nachr.*, 799–801 (1852), and *Auseinandersetzung* . . ., Leipziger Abh. v., vi., vii. (1857).

After a short interval as privatdocent at Munich, he was appointed Director of the Observatory of Göttingen in succession to Schur. Here he joined a brilliant circle of scholars who have made Göttingen world-famous. To a man of his wide interests in all branches of mathematics and physics the surroundings must have been very congenial; and to his growing reputation as an astronomer he added important achievements in other fields of research. Finally, in 1909 he was chosen at the age of thirty-six to succeed Vogel as Director of the Astrophysical Observatory, Potsdam, a position which he filled with distinguished success.

In reviewing his contributions to astronomy we may start with his work on photographic magnitudes, a long and sustained investigation, which required much perfection of detail as well as brilliance of conception. His first method, carried out at the Von Kuffner Observatory, was to measure the greyness of star-images taken out of focus. He set out to determine the variation of photographic effect with the length of exposure, as a step towards forming an absolute scale of magnitudes. It was already known that an increase of exposure-time has not the same effect as an increase of light-intensity—doubling the exposure is not so effective as doubling the brightness. Schwarzschild proposed the now well-known law that the photographic effect is proportional to It^p, where I is the intensity of the light, and t the exposure-time. For the constant p he found the value 0·675; but this appears to have been too low, and in the Göttingen Aktinometrie he redetermined the constant as 0·76—which means practically that an increase of exposure which might be expected to give a gain of four magnitudes in reality only gains three.

The fruit of this preliminary work was reaped when he came to Göttingen and, with the aid of his assistants, carried out the "Aktinometrie." This was a large undertaking, involving the determination of the magnitudes of all the stars brighter than $7^{m}\cdot5$ between 0° and +20° dec., and their reduction to an absolute scale. The great area of the sky covered by the survey necessitated the use of plates covering a large field 20° square. Naturally, in the outer parts of the field the extra-focal images were distorted and unsuitable for measurement, so Schwarzschild adopted the plan of displacing the image in a regular manner during the exposure so as to build up a square of uniform greyness; the device is known as the "Schraffierkassette." The immediate results of this work were of great interest; the visual magnitudes of all these stars had been measured at Potsdam, and the differences, photographic *minus* visual, gave the colour-indices of some 3500 stars. (The use of this quantity as a measure of colour seems to have been first suggested by him some years earlier.) In conjunction with similar work by King and Parkhurst, the Aktinometrie showed that spectral type is very accurately a function of the colour-index. It also brought out the fact that it is the stars of intermediate colour (yellow) which possess the largest proper motions, and that after a maximum about type G, the proper

motions diminish very rapidly for the redder types. This feature of the red stars was just beginning to be recognised; but the change of proper motion appeared particularly striking when exhibited as a function of a continuous variable, colour-index, instead of the broad divisions of spectral class.

In 1895, acting on a suggestion by Michelson, Schwarzschild introduced the plan of placing a coarse grating of parallel strips in front of the object-glass of a telescope so as to give diffraction images at a small distance from the principal image of each star. This device has since been used extensively both for measuring the colour, or effective wave-length, of stellar light and for establishing an absolute scale of magnitudes. Schwarzschild's first application was not to these purposes but to the measurement of double stars, the arrangement acting as a kind of double-image micrometer. The separation of the diffraction-images could be varied in a known manner by tilting the grating at different angles to the line of vision. Successful results were obtained with a 10-inch refractor; but no doubt there would be difficulties in working the arrangement at the end of a long telescope.

The task of determining accurate data for large numbers of stars inevitably leads the mind to consider the great problems of the structure of the stellar universe. Somewhat in the way that the Cape Durchmusterung led Kapteyn to his cosmical researches, so the Göttingen Aktinometrie may have turned Schwarzschild's thoughts to this wide field of discovery. But in his case there was already the influence of his teacher Seeliger, the pioneer in the mathematical theory of the distribution of stars. Schwarzschild's best-known work in this subject is his ellipsoidal hypothesis of stellar motions. It had been shown by Kapteyn that the individual motions of stars are not haphazard, but are especially directed in two favoured directions—that there are, in fact, two streams of stars. The directions of these streams, when referred not to the sun but to the stars as a whole, automatically become opposite to one another. In an approximate mathematical representation it was perhaps natural to take the streams as though they were two independent systems of stars passing through one another; but the theory proposed by Schwarzschild showed clearly that this division into two systems was not an essential part of Kapteyn's discovery. The important point to preserve in the formulæ was the æolotropic distribution of the motions—a greater mobility to and fro along one axis in space than in perpendicular directions. He noticed that this property could be represented by a simple modification of Maxwell's law of velocities; by setting the frequency of a velocity (u, v, w) proportional to $e^{-a^2u^2-b^2v^2-c^2w^2}$, the distribution stands in the same kind of relation to Maxwell's random distribution as an ellipsoid does to a sphere. The apparent antagonism between the two-drift and ellipsoidal hypotheses disappears if we remember that the purpose of both is descriptive. In a letter communicating his results to the writer, Schwarzschild said, "The formal comparison of our two hypotheses of distribution shows very well how nearly

the same they are. . . . Within our visible system the gravitation of the whole is certainly much stronger than the attraction of single stars at casual approaches. We could represent the stellar system as a homogeneous ellipsoid, and assume that the initial velocities of the stars are so distributed that this homogeneous ellipsoid always remains similar; then the velocities parallel to the greatest axis must be on the average greater than those parallel to the least. In that way one can try to render my hypothesis more plausible. But I freely admit that it has difficulties like yours. . . . You will certainly continue your researches on the two-drift hypothesis, as I shall on the ellipsoidal; and by this competition I hope the solution of the whole marvellous problem may be accelerated." The ellipsoidal theory has great mathematical elegance both in its conception and its application. Whilst the two-drift theory has often been preferred in the ordinary proper-motion investigations, on account of an additional constant in the formulæ which gives it a somewhat greater flexibility, the ellipsoidal theory has been found the more suitable for discussions of radial velocities and the dynamical theory of the stellar system.

The study of proper motions leads naturally to the question of the distribution of the stars in space. In an elementary conception of this problem we may suppose that each part of space contains stars of varying degrees of luminosity in proportions determined by some standard law, and with various speeds also following a uniform law, but there will probably be a thinning out in the number of stars per unit volume as we recede from the centre of the stellar system. As knowledge has progressed, much complexity has been added to this simple scheme; we have had to step aside to investigate star-streaming or the varying behaviour of different spectral types. But the luminosity law and the density law, involving the specification of the shape and dimensions of the stellar system, must remain a fundamental aim of research. It is theoretically possible to deduce the two laws from counts of stars between different limits of magnitude together with the mean parallax (or parallactic motion) for each magnitude. The general solution of this problem was given by Schwarzschild; it involved the solution of certain integral equations by an original method of considerable mathematical interest. In practice it is usually more desirable to use a less general method, assuming particular forms of the laws which give a sufficient approximation; here Schwarzschild followed more closely the lines laid down by Seeliger, but by his keen insight he brought the mathematical discussion into an admirably clear form. His latest and fullest discussion of the observational data is given in the *Sitzungsberichte* of the Berlin Academy, 1914, where the different spectral types are treated separately. Workers in this kind of statistical research owe a grudge to the discovery of "giant" and "dwarf" stars, which has played havoc with some of the hoped-for simplicity of the problem, and seems to have placed definitive results for the moment out of reach; but step

by step the knowledge of stellar distribution is improving, and Schwarzschild's mathematical treatment has notably contributed to the advance.

In solar physics Schwarzschild has left his mark by his theory of radiative equilibrium of the sun's atmosphere, published in 1906. Three possible modes of transfer are recognised by which the heat squandered into space from the outer layers may be replaced from the stores of energy within. Conduction can scarcely play a significant part, and it has usually been considered that convection currents are the main agents of transfer, as in the terrestrial atmosphere. But at the high temperature of the sun it is more likely that radiation outweighs all other causes—certainly in the interior, and probably also in the atmosphere proper. In this case the state of equilibrium must be determined by the condition that each element radiates just as much energy as it gains by absorption of the radiation passing through in all directions. In proposing this state of radiative equilibrium, Schwarzschild was unwittingly following the theory put forward by Sampson twelve years earlier; but by introducing Stefan's law, that the density of radiation varies as the fourth power of the temperature, he was able to give definite shape to the formulæ. He showed also that the radiative hypothesis appears to account satisfactorily for the observed degree of darkening of the sun's limb.

An account of Schwarzschild's achievements necessarily has a disjointed appearance, so varied were the subjects he pursued. We can only refer very briefly to some other scientific contributions. Among his theoretical researches with a definitely astronomical application may be noted his calculation of the light-pressure on small solid particles. He showed that the increase in the ratio of light-pressure to gravitation with diminishing size ceases to hold when the dimensions of the particle are comparable with a wave-length of light, so that there is a maximum value of this ratio (for solid particles), which in the case of the sun is about 20. Since the repulsion observed in comets' tails is believed frequently to exceed the limit of twenty times the gravitation, this conclusion is of considerable practical interest. Schwarzschild also made an important step in the discussion of the equilibrium of the pear-shaped figure of rotating fluid in connection with Poincaré's theory of exchange of stabilities. In geometrical optics he devised a reflecting telescope with two concave mirrors, which should give a large field of good definition (equivalent to that of the astrographic telescopes) for a focal ratio of 1 in 3. A preliminary memoir, in which, however, he expressly disclaims originality, contains what is probably the most concise and clear account to be found anywhere of the use of the characteristic function (or eikonal) in practical optics. Other branches of research were so diverse as the electron theory and the navigation of airships; for the latter he published suitable tables in 1909, and later devised a special form of sextant. The recent upheaval of the funda-

mental ideas of physics interested him deeply; a paper by him on the relativity explanation of the motion of the perihelion of Mercury is not yet accessible in this country, and during his last illness he corrected the proofs of a paper on the quantum theory for the Berlin Academy.

The wide range of his contributions to knowledge suggests a comparison with Poincaré; but Schwarzschild's bent was more practical, and he delighted as much in the design of instrumental methods as in the triumphs of analysis. It is interesting, though sometimes misleading, to trace a unity in the varied researches of a man's lifetime, for it often happens that a thread of association binds the whole together. But Schwarzschild's versatility baffles any such summary; his joy was to range unrestricted over the pastures of knowledge, and, like a guerilla leader, his attacks fell where they were least expected. He sought no unity save the one bond which unites together all branches of scientific endeavour. "Mathematics, physics, chemistry, astronomy, march in one front. Whichever lags behind is drawn after. Whichever hastens ahead helps on the others. The closest solidarity exists between astronomy and the whole circle of exact science. . . . From this aspect I may count it well that my interest has never been limited to the things beyond the moon, but has followed the threads which spin themselves from there to our sublunar knowledge; I have often been untrue to the heavens. That is an impulse to the universal which was strengthened unwittingly by my teacher Seeliger, and afterwards was further nourished by Felix Klein and the whole scientific circle at Göttingen. There the motto runs that mathematics, physics, and astronomy constitute one knowledge, which, like the Greek culture, is only to be comprehended as a perfect whole."*

Soon after the outbreak of war Schwarzschild was placed in charge of a meteorological station for the German army at Namur. He was afterwards attached to the artillery staff, at first in France and later on the Eastern front. He received the order of Knight of the Iron Cross. As might be expected, the German army organisation took care to give scope to his scientific ability, and in 1915 November he contributed to the Berlin Academy a paper on "The Effect of Wind and Air-density on the Path of a Projectile": publication has, of course, been postponed. On military service he contracted a disease which ultimately proved fatal. After a long illness, attended with much suffering, he died on 1916 May 11. His lively and attractive character and his readiness to co-operate with others brought him into cordial relationship with astronomers in many parts of the world, and his early death is felt as a deep personal loss.

He was elected an Associate on 1909 June 11. A. S. E.

* Admission-speech before the Berlin Academy of Science, 1913.

Proceedings of Observatories.

The following reports of the proceedings of Observatories during the past year have been received from the Directors of the several Observatories, who are alone responsible for the same.

Royal Observatory, Greenwich.
(*Director, Sir F. W. Dyson, Astronomer Royal.*)

As explained in last year's report, the activity of the Observatory has been necessarily circumscribed by the war. It has been possible, however, to keep up all observations where continuous record is required. Measurements and reductions are in a more forward state than might have been anticipated.

Transit-Circle.—6243 observations have been obtained. The transits are all reduced to apparent place, and the zenith distances as far as the end of October. The Sun has been observed on 125 days and the Moon on 89 days.

The catalogue of stars down to $9^{m}{\cdot}0$ in the Oxford Astrographic Zone (Dec. $+24^{\circ}$ to $+32^{\circ}$) has been completed. It contains 12,000 stars, with five observations each in most cases. Proper motions have been determined for all but 250 of the stars, for which the material was insufficient. Investigations have been made of parallactic motion, star-streaming, and some questions of stellar statistics.

Altazimuth.—The use of this instrument has been restricted to supplementing the observations of the Moon made with the transit-circle. The Moon was observed 10 times on the meridian and 25 times in other azimuths. With one or other of the two instruments the Moon was observed on 111 days. The mean correction in right ascension required by the *Nautical Almanac* is $+^{s}{\cdot}92$, and by the *Connaissance des Temps* (depending on the revised Delaunay tables) is $+^{s}{\cdot}28$.

Cookson Floating Telescope.—215 plates, each exposed on a group of 4 or 5 Talcott pairs, have been taken, and also 6 plates for the determination of scale. The measurement and reduction is well in hand, and it is hoped that the variation of latitude results for 1916 will be ready for publication in March.

Occultations.—8 disappearances and 2 reappearances of stars occulted by the Moon have been observed. The results have been communicated to the Society.

28-inch Refractor.—529 double stars have been measured by M. Jonckheere. These include—

170	double stars	with a	separation	$<2''$
145	,,	,,	,,	$2''$ to $3''$
120	,,	,,	,,	$3''$ to $4''$
56	,,	,,	,,	$4''$ to $5''$
38	,,	,,	,,	$>5''$.

During the year 70 new double stars were discovered, as well as a bright planetary nebula which had curiously escaped spectroscopic surveys.

The telescope was largely used for identification of stars in the preparation of a catalogue of double stars discovered since 1905. This catalogue of M. Jonckheere's was in the printers' hands a year ago, but a delay in publication was caused by fire. It has been set up again, and will be finished very shortly.

Thompson Equatorial.—173 plates have been exposed for parallax determinations and put away without being developed to await a second exposure; 202 plates have been re-exposed at the end of the half cycle.

24 plates of Jupiter's satellites were taken on 14 nights near Aug. 20, and 18 on 13 nights near Dec. 20. These have been taken at the request of Dr. de Sitter, and are in continuation of a series taken for him at the Cape when Jupiter was further South. The first batch has been forwarded to Dr. de Sitter.

6 photographs of Jupiter have been taken for place in connection with Mr. Knox-Shaw's observations of the eighth satellite.

16 photometry plates have been taken of Kapteyn's areas, mostly at declination $+15°$.

During the year 45 parallax plates have been measured, and provisional values of the parallaxes of 21 stars determined.

Astrographic Equatorial.—The instrument has been out of use most of the year. 54 fields have been taken with short exposures for comparison with earlier photographs. The places of the stars in vol. iii. of the *Astrographic Catalogue* have been compared with earlier catalogues. Also a direct comparison of plates about twenty years apart is being made in the duplex micrometer, with the view of examining all the stars in the *Bonn Durchmusterung* in the Greenwich zone for proper motion. At the request of Mr. Innes, a number of pairs of plates have been sent to him at Johannesburg for the determination of proper motions by means of a blink micrometer.

Photoheliograph.—Photographs of the Sun were obtained with this instrument on 227 days during the year 1916, of which about 20 were days of poor definition. At the Cape Observatory photographs were obtained on no fewer than 332 days during the year ending 1916 October 31; leaving 17 days unrepresented by satisfactory photographs from the combined record of the two observatories. To fill these gaps 11 photographs from Dehra Dûn and 2 from Srinagar have already been received, and it is hoped that

one or other of the Indian observatories will be able to supply plates for the four remaining days.

The solar activity has continued to increase during 1916; March, June, and October being months specially prolific in Sun-spots, and the year closed with a fine succession of large spots in the N.E. quadrant of the disc. The mean daily spotted area for the whole year may be roughly estimated as not far short of 1000 millionths of the Sun's visible hemisphere, as compared with about 750 for 1915, 152 for 1914, and 7 for 1913.

The great increase in the solar activity and the reduction in the staff of the department has inevitably thrown the measurement and reduction of the solar photographs into arrear. Nevertheless by the close of 1916 all photographs had been measured in duplicate up to and including 1916 May 6, and the reductions of the areas and positions of the spots and faculæ had been completed, and the copy for press of the Daily Results prepared up to the end of October 1915.

Personal.—Three of the junior assistants and nineteen computers are absent on Military Service. Mr. Jones is lent to the Inspection Department of the Woolwich Arsenal, and Mr. Edney to the Hydrographic Office.

Royal Observatory, Cape of Good Hope.
(*Director, Mr. S. S. Hough, H.M. Astronomer.*)

Transit-Circles.—The programme of observations of the Backlund-Hough stars in conjunction with a selected list of stars from Boss's fundamental catalogue was brought to completion early in November. In connection with this programme the following observations were secured during the year:—

Observations of Right Ascension:—

Number of meridian transits . . .	4557
Determinations of collimation by collimators	84
,, ,, ,, by reflexion and reversal	25
Determination of level	711
,, ,, azimuth	127
Observations of meridian marks . . .	1223

Observations of Zenith Distance:—

Determinations of Z.D.	4981
,, ,, runs	324
,, ,, nadir	698
,, ,, flexure	60

Included with these observations are:—

Observations of the Sun on 139 days.
,, ,, Mercury ,, 53 ,,
,, ,, Venus ,, 93 ,,

On completion of this programme the instrument was subjected to a complete overhaul, and a new programme of observations of close circumpolar stars, arranged with special reference to the determination of the constant of aberration, was commenced. A sketch of the method of arrangement, which it is anticipated is capable of leading to a determination of the constant referred to, with the minimum of liability to systematic error, and with an accidental error not exceeding $\pm 0''.01$ as the result of a single year's observations in either element, has been communicated to the Society.

In connection with this new programme the following observations were obtained during the year:—

Observations of Right Ascension:—

Number of meridian transits . . .	159
Determinations of collimation by collimators	3
,, ,, level	27
Observations of meridian marks . . .	44

Observations of Zenith Distances:—

Determinations of Z.D.	152
,, ,, runs	10
,, ,, nadir	26

The programme of observations by Mr. J. Voûte for parallax determinations with the non-reversible transit-circle was brought to completion on August 16.

The observations during the year consist of:—

3039 evening transits } of parallax and
4731 morning transits } comparison stars.
12 transits of azimuth stars.

This instrument was also used for occasional time determinations during the time that the new instrument was undergoing overhaul.

Heliometer.—Observations of the major planets at the time of opposition have been continued as in previous years, and the following obtained:—

Opposition of Saturn * .	17 obs.	in distance	on 3 nights.
,, ,, Neptune .	48 ,,	,, ,,	on 6 ,,
,, ,, Mars .	44 ,,	,, ,,	on 4 ,,
	4 ,,	,, position-angle	on 1 night.
,, ,, Jupiter .	12 ,,	,, distance	on 6 nights.
	12 ,,	,, position-angle	
with standard pair of	12 ,,	,, distance	
stars	12 ,,	,, position-angle	

* In addition to 32 observations in distance on 4 nights in the year 1915.

Victoria Telescope and Astrophysical Laboratory.—The telescope was in use for the photography of stellar spectra on 151 nights during the year.

171 plates, chiefly of long exposure on faint stars, for the determination of radial velocities, were secured, in addition to 19 daylight plates and 16 focus plates. The programme of observations with the 4-prism spectrograph and long camera, commenced in 1908 July, was completed before the end of the year.

Experiments have since been made with the use of a shorter camera with a view to the extension of the programme to fainter stars than those included in the previous list.

In the laboratory 420 plates have been measured with the Hartmann Comparator, inclusive of repetition measures of a considerable number that had been previously measured.

With the "wave-length" measuring machine 23 plates have been measured by Mr. Voûte for the determination of possible displacements of lines in spectra of different star types.

Papers by Dr. Lunt "On the Orbit of the Spectroscopic Binary σ Puppis" and "On the Orbits of the Spectroscopic Binaries α Orionis and α Scorpii" have been communicated to the *Astrophysical Journal.*

The Astrographic Telescope.—With the astrographic telescope the following plates for the determination of stellar magnitude have been obtained:—

	No. of Plates.
Exposures on a single region . .	109 (218 exposures)
,, on two regions . . .	4 (16 ,,)
Photographs of Pleiades . . .	2 (16 ,,)

Photographs of 20 star regions for the determination of stellar parallax work were obtained, including 51 plates with exposure at a first epoch, 28 with exposure at the second epoch, and 7 with one epoch only.

5 "chart" plates have been repeated for the determination of proper motion.

Of the parallax plates, all which have been developed have been measured by means of the measuring apparatus of the Zeiss Stereo-Comparator. These plates have been obtained and measured by Mr. Voûte in connection with his general programme of observations for stellar parallax. He has also used the same apparatus for the measurements of some 37 photographs of double stars.

Photoheliograph.—Daily photographs of the Sun to supplement the Greenwich series have been taken on 333 days. In all 691 photographs were taken and forwarded to Greenwich. At the request of the Astronomer Royal the duplicate photographs are taken when possible at an interval of not less than 15 minutes after the originals. In this way the existence of small sun-spots, of short duration, has been detected.

Occultations.—Twenty-six separate phenomena of occultations of stars by the Moon have been observed during the year, viz.:—

Disappearances at dark limb . .	15
Reappearances „ „ „ . .	11

Reductions of Meridian Observations.—The reductions of meridian observations to apparent place have been completed to 1916 December 18 in both elements. The reductions to mean place have been computed for all observations to 1916 February 8, and the mean places formed to 1915 November 30. The results for the years 1912–14 have been entered in ledgers with a view to the formation of a catalogue which will be based on the observations of the years 1912–16.

The detailed results of the observations of the years 1909–11 have been passed through the press. The printers have since reported that the bulk of the type set up has been destroyed by fire. Duplicate copies in proof have since been furnished to them.

The results, together with a discussion, of the meridian observations of the Sun, Mercury, and Venus during the years 1907–11 have been issued as vol. viii. part iv. of the *Cape Annals.*

"Carte du Ciel" Reductions.—Revision work, consisting of comparisons with the C.P.D. and comparisons of overlapping areas, has been continued.

During the year the discordances between overlapping areas have been examined for 222 pairs of overlapping quadrants, and the identification of the C.P.D. stars for 360 plates. The final copy for press has been completed for 297 plates.

As no overlap was available for the extreme zone ($-51°$), the results for this zone have been verified by a rough re-measurement of all stars down to the 11th magnitude.

Vol. iv. of the *Cape Astrographic Zones*, containing rectangular co-ordinates and measures of diameters of stars contained on the astrographic plates in zone $-44°$, has been passed through the press, but the sheets have been destroyed by fire at the printers. The printing of results has been discontinued during the war.

Counts of stars, grouped according to magnitude, have been made for 184 plates.

In connection with the investigations of stellar magnitude arising out of the conversion of the diameters of the astrographic zones into photographic magnitudes, a statistical paper on "The Question of the Extinction of Light in Space and on the Relations between Stellar Magnitudes, Distances, and Proper Motions" has been communicated to the Society.

Miscellaneous.—The time-signal service, meteorological observations, and seismograph records have been maintained as in previous years.

Royal Observatory, Edinburgh. Director, Professor R. A. Sampson, Astronomer Royal for Scotland.

General.—Astronomical work has been much restricted during the year owing to occupation of the staff upon war work. Mr. Storey and Mr. Wrigley have been absent throughout the year. For the latter part Miss E. A. Falconer has been absent also.

Transit-Circle and Clocks.—Close attention has been given to time service and the going of the clocks. Two experimental clocks have been added, and are housed in the clock-cellar under circumstances of constant temperature and pressure. One of these is by the Synchronome Company, and is made with Mr. W. H. Shortt's gravity escapement. The other is by Mr. E. T. Cottingham, F.R.A.S., with a version of Gill's escapement. Both have been fitted with scales and reading microscopes, by which the arc can be read to about 1″. These two clocks and Riefler have all shown a high degree of accuracy. Riefler in particular, which was cleaned by Mr. Cottingham in March, has gone admirably. The Synchronome clock was set up in March and Mr. Cottingham's in September. Both promise to be on an equal level with Riefler, if time is allowed for working off certain initial difficulties—for example, the Synchronome clock has shown for several months a daily increase of gaining rate of $0^{s}\cdot02$, due presumably to shrinkage of the pendulum rod, which is a fully aged and certificated piece of invar. A large amount of information has been acquired as to the barometric equations and temperature equations of these and the other clocks, of the variation of arc with pressure, of rate of decline of arc when the impulse is withdrawn, and other features. Continuous readings of arc and simultaneous comparisons of the clocks upon the chronograph are kept up. These, when analysed, will give further information as to systematic variations of arc and rate, and will serve to isolate anomalous variations of rate, which indeed appear to be very small. One difficulty in connection with precision time-work is the chronograph error. The moving pieces of a chronograph are as a rule fairly massive, and must be started from rest for each record, besides being operated somewhat indirectly. When anomalies occur in a comparison it is usually impossible to say how much may be due to the chronograph up to, say, $\pm^{s}\cdot02$ or more. To meet this difficulty experiments have been made to record the actual current as it leaves the clock itself; the general principle is that of the oscillograph or Einthoven galvanometer, the weak clock current being carried between the poles of a powerful electro-magnet and deviation recorded photographically. As is known, such a method can be worked so as to be entirely free from relative lag. Encouraging results have been obtained, and it is hoped to develop a practical system that will permit reliable comparisons to be made much within the above limit.

Wireless Time-Signals.—The rhythmic time-signals from Paris have been taken on 246 nights and the comparisons telegraphed to

Paris Observatory. The mean difference found is *Paris–Edinburgh* = $+0^{s}\cdot02$, compared with $+0^{s}\cdot05$ last year.

Solar Spectroscope.—Six plates of good quality have been obtained during 1916, each with about 10 exposures on East and West limbs at the Sun's Equator. The region is the neighbourhood of λ6300.

Equatorials.—No work has been done with these during the year, but preparations have continued with the purpose of taking up photoelectric determination of magnitude. Mr. Baker has made and filled some experimental cells. Great trouble has been found in securing seals for the platinum electrodes which should not crack. Several seals made by professional glass-blowers have, without exception, broken down.

Astrographic Chart. — Calculation of plate constants and standard co-ordinates for certain positions remains to be done, and has not been advanced during the year. Counts have been made of the stars of different magnitudes, and the results are now under examination.

Seismograph.—Observations were made regularly, the records read, and the results communicated to Shide.

Meteorological Observations were made regularly as heretofore.

Armagh Observatory.

The work was continued on the same lines as during the last few years until the end of September. Dr. Dreyer then resigned the office of Astronomer, which he had held for 34 years, and removed to Oxford in order to devote his whole time to the new edition of Tycho Brahe's works.

Mr. J. A. Hardcastle has since been appointed to the vacant post, and will assume charge of the Observatory in the Spring. In the meantime the meteorological observations only are being continued.

Cambridge Observatory. (*Director, Professor A. S. Eddington.*)

Both the assistants have been absent on war service throughout the year, Mr. Hartley as Naval Instructor, and Mr. Entwistle as Second Lieutenant. There is consequently very little progress to report.

Some photographs of short-period variable stars have been taken with the Sheepshanks telescope, and a series consisting of 129 ten-minute exposures on SU Aurigæ has been completed. Preliminary trials of various methods of comparing the diameters of

the images have been made, and the systematic measurement of the series is now in progress.

Demonstrations in practical astronomy have been given to students by the Director on evenings during the two winter terms.

By the kind assistance of Mr. J. A. Aldis and Mr. C. P. Butler it has been possible to continue the Saturday evening exhibitions of celestial objects with the Northumberland Equatorial. The attendance in the Lent term was often large, but during the present winter the weather has been persistently unfavourable.

Solar Physics Observatory, Cambridge University.
(*Director, Professor H. F. Newall.*)

Spectroheliograph.—Photographs of the Sun's disc in K_{2-3} light have been obtained on 108 days, and photographs of the prominences at the limb on 92 days.

The solar activity continues to increase in general, but several intervals of comparative quiescence with respect to spots and flocculi have occurred during the year.

The 18-inch and 6-inch mirrors were dismounted on April 12, and were replaced on April 20 after being resilvered.

The 12-inch photovisual objective was dismounted on October 26, and after the deposit which had gradually accumulated during recent years on the surfaces of the component lenses had been cleared away, it was remounted on the same day.

For the period 1915 July 2–1916 June 30, the Director of the Kodaikánal Observatory has sent 315 spectroheliograms showing the solar disc in K_{2-3} light. Of the 51 days missed in the Kodaikánal records during this period, the Cambridge record has photographs for 22 days.

Photoheliograms.—Daily photographs taken with the photoheliograph at Dehra Dûn have been received, and the negatives are stored at the Science Museum, South Kensington. Positive paper prints have also been received from Dehra Dûn.

Solar Spectrum.—A revision of the origins assigned in Rowland's Tables of Solar Wave-lengths has been made in the region of the spectrum ranging from λ3900 to λ5900. Since Rowland's Solar Tables were published in 1895-98, many records of laboratory wave-lengths have been published, and reference to these has shown that although the vast majority of Rowland's identifications are confirmed, there is a fair proportion which, on the available evidence, must be revised. Many lines left unidentified by Rowland have been traced to their chemical origins by reference to the new work.

Stellar Spectra.—A long series of spectra of various carbon compounds has been investigated, chiefly with respect to their relation to celestial spectra of various types.

Work in the Laboratory.—The work in connection with the

hydrocarbon spectrum has been continued. The photographs taken with the high dispersion spectrograph which required very long exposures, from eleven to fifty hours, suffered in definition in consequence of the shifting of the spectrum during exposure. This has been in large measure remedied by providing round the prism-box a felt jacket and an electric heater arranged in coils in the cover.

A preliminary note announcing the identification of Fraunhofer's Group G in the solar spectrum with the hydrocarbon band λ4314 was published in the *Monthly Notices* (vol. lxxvi. p. 640).

For an investigation dealing with the determination of the origin and conditions of occurrence of the various types of carbon spectra, a suitable spectrograph of small dispersion, capable of recording the spectrum from λ6600 to λ3600, has been successfully elaborated, mainly from portions of the physical apparatus presented by the late Lady Huggins. It now gives satisfactory definition throughout this long range of spectrum.

Investigations in Atmospheric Electricity.—Investigations relating to atmospheric electricity have been continued. In a paper "On Some Determinations of the Sign and Magnitude of Electric Discharges in Lightning Flashes," published in the *Proceedings of the Royal Society* (vol. xcii. A, pp. 555–574), Mr. C. T. R. Wilson discussed the results of about 100 determinations of the sudden changes produced in the vertical electric field by lightning discharges. In the case of about 50 of these discharges it was found possible to get measurement of the distance of the lightning from the place of observation by timing the arrival of the sound of the thunder. From the data obtained, an estimate was deduced of the average quantity of electricity discharged in lightning flashes; this amounts to about 30 coulombs per flash. The paper contains an account of the apparatus and methods used at the Observatory for the investigation of atmospheric electricity.

The apparatus needed for securing automatic photographic records of the electrical effects has now been installed and is found to work well.

Personal.—The Assistant Director, Mr. Stratton, has been with the British Expeditionary Force in France since 1915 July. He was gazetted (1916 April 8) Major in the Royal Engineers (20th Signal Company), was mentioned (second time) in Sir Douglas Haig's despatches, and was awarded the D.S.O. on 1917 January 1.

The First Junior Observer, Mr. W. E. Rolston, who received his commission and left the Observatory in 1915 June to join the 2/5th Weald of Kent Battalion (The Buffs), was gazetted Captain, 1916 April 12.

The Second Junior Observer, Mr. W. Moss, took up duties on 1916 March 29, in the Inspection Department at Woolwich Arsenal.

The Resident Attendant, W. H. Manning, has been engaged since 1915 May in munition work.

Dunsink Observatory.
(*Director, Prof. H. C. Plummer, Royal Astronomer of Ireland.*)

It was mentioned in last year's report that the weather of 1915 was considered more unfavourable for observations than in previous years, though in the absence of comparative records this was a matter of general inference only. It can now be stated definitely that the conditions in 1916 were distinctly worse than in 1915, and gave a total of 49 fine nights as against 80 in the previous year. As a "fine" night merely implies a clear interval of some hours' duration, with no regard to the quality of the seeing, and a considerable deduction must be made for bright moonlight and for the very short nights of midsummer, it will easily be understood that the photographic work on variable stars has been carried on under the greatest difficulty. A total of 193 plates have been taken on 57 nights, and 170 plates have been measured.

During the year papers on three variables in one region of Lacerta, including V and X Lacertæ, on the eclipsing binary TT Aurigæ, and on the irregular variable RS Camelopardalis, have been prepared and communicated to the Society. Other miscellaneous work also published includes a statistical investigation of the Minor Planets.

The time-ball in Dublin has been re-erected in a position at the end of the South Wall, where it is visible to the shipping in the river. Determinations of time were made with the Pistor and Martins meridian circle on 76 nights. The legal adoption of standard time in Ireland on 1916 August 23 is an event which deserves mention.

The staff, consisting of the Director and Mr. Martin as assistant, remains unchanged.

Glasgow Observatory.
(*Director, Professor L. Becker, Assistant, James Connell.*)

The Director has been on leave of absence since the end of March. The usual routine work connected with the time service and meteorological observations has been carried on by the assistant.

At the beginning of June a number of chronometers and watches were deposited at the Observatory by the Admiralty; these are compared daily with the Standard Mean Time Clock and their errors and rates derived.

The Astrophotographic lens belonging to the large spectrograph has been lent to the War Office.

Liverpool Observatory, Bidston.
(*Director, Mr. W. E. Plummer.*)

The work of this Observatory has been both hampered and curtailed on account of the severity of the police regulations mentioned in the last report. These inconveniences continue, and the observations have been confined to those which are necessary to ensure the accurate determination of time-signals and to fulfil other services of a routine character which this Observatory has been accustomed to render to the port and the mercantile marine.

In this connection it may be mentioned that the number of chronometers deposited for test has been less than at any time within the last twenty-five years—an index of the effect of the war in decreasing the tonnage using the port.

The meteorological and seismological work, not being disarranged by the untoward conditions that have affected the astronomical, has been pursued without interruption, but that does not call for any particular mention here.

The diminished activity of the Observatory in its several departments of usefulness is entirely attributable to war conditions.

Radcliffe Observatory, Oxford.
(*Director, Dr. Rambaut, Radcliffe Observer.*)

The programme of work with the 24-inch refractor on the proper motion of stars in Professor Kapteyn's "Selected Areas" has been carried on during 1916 on the same lines as in recent years—so far at least as the reduction of the staff and bad weather would permit; but, owing to difficulties arising from these two causes, the year has not been a successful one.

Most of the areas of which photographs were wanting in order to complete the programme come into position in the autumn and early winter months, and during the recent autumn the state of the sky has been peculiarly unfavourable, so that, although special early morning watches were again arranged during the months of September, October, November, and December, with a view to overtaking arrears, and although no effort was spared to utilise every possible opportunity, the number of these outstanding fields, though slightly diminished, is still considerable. During this period only 5 plates could be secured, and of these two were considered unsatisfactory. The exacting character of this work renders it peculiarly difficult in a climate like that of Oxford. During the year 25 proper motion photographs were secured —each plate requiring two exposures of 30 minutes. Unfortunately, 5 of these plates are incomplete or imperfect, leaving only 20 plates which are considered good enough for the purpose in hand. Twelve plates, exposed but not developed, were packed in an air-tight box, to be exposed to the same region of the

sky when ten years have elapsed. This makes twelve dozen proper motion plates which have now been stored in this way.

Observations were made on June 2 and 6, by the aid of the 18-inch refractor, for the purpose of determining the position of the polar axis of this instrument. These observations show that the errors in azimuth and altitude have changed very slightly since the axis was last adjusted on March 17 of the previous year, and are still less than $5''{\cdot}5$ in either co-ordinate. This result indicates a very satisfactory degree of stability in the mounting of the instrument.

The 10-inch Barclay equatorial has been used by Mr. Barrett as in former years for observing a selected list of variable stars. Four stars have chiefly engaged his attention during the year, viz. ST Draconis; VV Aurigæ; 4, 1913 Tauri; and 5, 1913 Arietis. Of these stars 310 observations (involving 985 comparisons of brightness) on twelve nights have been secured.

The work of reducing and preparing for press the results deduced from parallax plates taken in recent years with the 24-inch refractor has proceeded but slowly, chiefly in consequence of the reduction of the personnel of the Observatory. No astronomical computations whatever could be effected during the two holiday months, July and August, as the meteorological duties and the reduction of the meteorological observations occupied the whole attention of the available members of the staff. The reading of proof-sheets of a new volume of observations also occupied a good deal of time. With these interruptions, Mr. Robinson has been engaged chiefly upon the astronomical reductions. Part of his work consisted in determining the photographic magnitude of each star observed for parallax by comparison with a polar plate. In this way 5650 separate determinations of magnitude for 2390 stars have been made, their values carried into the card-catalogue, and the means formed. The weighted means of the separate results for the parallax of each star have also been taken, and their probable errors computed. An investigation has also been made into the possible cause of errors depending on magnitude which affect some of the parallax results.

Volume li. of the *Radcliffe Observations* was printed and distributed early in the year. This volume, containing the usual meteorological results for the years 1911–1915, includes also the observations of underground temperature at the Radcliffe Observatory made daily, by means of platinum-resistance thermometers, during the twelve years 1898–1910, with a discussion of the principal results to be deduced from them.

University Observatory, Oxford.
(*Director, Professor H. H. Turner.*)

The reductions for the Vatican plates of the Astrographic Catalogue have gone on steadily, being only limited by the supply of measures from Rome. Zone $+59^{\circ}$ was completed, and the first

twelve hours of zone $+58^\circ$ are fully reduced, which is as far as measures are available. Standard co-ordinates have been computed for $+57^\circ$, $+56^\circ$, and as far as 17^h in $+55^\circ$, leaving only seven hours' standard co-ordinates to complete the whole Vatican portion ($+64^\circ$ to $+55^\circ$) in this respect. The second printed volume of measures (zone $+63^\circ$) was issued in April last; and the first third of the volume for $+62^\circ$ is in type. The war has naturally delayed the printing and interfered with the work generally, but the amount accomplished during the year in spite of various delays may be regarded with satisfaction.

The analysis of meteorological observations has been continued during the year, the chief results being summarised in two papers to the Royal Meteorological Society (*Q.J.*, xlii., 1916, p. 163, and xliii. p. 43). The first paper dealt with Sunderland rainfalls, and Paris rainfalls and temperatures, showing the confirmation of the "chapters" in all these series. The second paper was an analysis of rainfall at twenty-eight stations scattered over Europe for the years 1850–1905, showing confirmation of the "chapters," giving a closer specification of the separating dates, and showing also confirmation of the five-month period which had been found in earlier papers. Many other series have also been reduced and are nearly ready for publication. It seems clear that no analysis of meteorological records over a long series of years can be effective unless account is taken of this division into separate chapters, and, further, that the study of the chapters may be fruitful in other directions. Mr. Bellamy has nearly completed a laborious analysis of the *daily* readings of barometer at the Radcliffe Observatory, Oxford, from 1853–1915; and by the courtesy of Dr. Dreyer and the Rev. Charles Faris has collected some of the Armagh records (mainly unpublished) for the eighty-four years from 1833 to 1916.

The Director has continued his superintendence of the seismological work at Shide. A number of Milne-Shaw machines are now being made for replacing the early Milne pendulums, the expense being partly defrayed by a generous private benefaction. The best records for 1914 have been fully discussed, and derived corrections to the tables for P. and S. are nearly ready for adoption. They indicate a curious anomaly near the epicentre, probably due to the anomalous structure of the earth's crust; and the corrections carry with them the possibility of double reflection of waves, which seems to afford an explanation of certain observed discordances at distant stations. The discussion is given fully in the 21st Report of the Seismological Committee to the British Association.

The editing of Baxendell's Variable Star Observations, in collaboration with Miss Blagg, is approaching completion. T Herculis (revised), R Persei, R Sagittæ, R and T Serpentis, T Tauri, and R and S Ursæ Majoris have been dealt with during the year. The conclusion that the Argelander-Chandler terms are not justified by observation has been steadily confirmed, and was adopted by the Rev. T. E. R. Phillips in his able address to the British Astronomical Association.

Only one further note (dealing with the single Melbourne zone $-65°$) was published during the year on the astrographic magnitude scales; but a number of counts were made and are nearly ready for publication.

Three more notes on stars with large P.M. have been added to the series: the ninth and eleventh by Mr. R. J. Pocock of Hyderabad, who measured some Oxford plates while his other work was brought to a standstill (owing to loss of plates in the *Persia*); the tenth note by Mr. Bellamy and Mr. J. D. M'Neile of Wellington College.

The number of students in Oxford at present is of course small, but there have been various calls for popular lectures to troops, which have been promptly met.

The Observatory has to record with sorrow the death of Mr. John Mullis, who was in its service forty years, and performed a variety of duties with great efficiency.

The Coats Observatory, Paisley. (*Convener, Dr. Ferguson.*)

During 1916 the work of the Observatory—astronomical, meteorological, and seismological—has been carried on as usual, without interruption. Climatalogical observations are reported regularly to the Meteorological Office, and the recording instruments have been kept in good order.

Temple Observatory, Rugby School.
(*Director, Mr. G. M. Seabroke.*)

This Observatory has been used for educational purposes as usual during the year, and the attendance of boys has been good. No one has had time during the year to do more than carry on school work.

The Hill Observatory, Salcombe Regis, Sidmouth.

The work on the spectra of the fainter stars has been continued, the working list containing all the stars of the revised Harvard photometry between magnitude 5·0 and 5·59. In Bulletin No. 5, a new catalogue of 287 stars was published in November.

In September the third assistant, Mr. H. E. Goodson, left for war service, and as he was the only assistant remaining, the others having joined the colours, the Observatory was closed. The services of Mr. Lake, as caretaker, were retained to keep the instruments in proper condition and to set going the electric heaters in inclement and specially damp weather.

The buildings and instruments are all in order.

The Hill Observatory was incorporated by the Board of Trade in 1916 July 25. A copy of the Memorandum and Articles of Association has been sent for the information of the Society.

Imperial College, South Kensington. (*Professor A. Fowler.*)

The astronomical instruments were chiefly used for the instruction of students, but occasionally also for spectroscopic observations of the Sun.

Research work in the spectroscopic laboratory has been mainly directed to the enhanced lines of silicon, carbon, and oxygen in relation to their occurrence in stellar spectra, and with a view to the identification of series lines. The region covered by the investigation is from λ1900 to λ7200, and the spectra have been photographed under a great variety of experimental conditions. In the case of silicon, attention has already been drawn to the identification of four additional lines of the fourth group in B stars (*M.N.*, lxxvi. p. 196). Other results of considerable interest have also been obtained, and will be published when the determination of wave-lengths is completed. Mr. J. S. Clark and Mr. J. Brooksbank, of the Physics Department, have collaborated in this work.

The demonstrator, Mr. W. E. Curtis, is still absent on military service, having received a commission in the Royal Engineers on his return from Gallipoli. The acting demonstrator, Mr. F. S. Phillips, has been almost entirely occupied in the X-ray department of the War Office. Other work connected with the war has also absorbed a considerable amount of time.

Stonyhurst College Observatory.
(*Director, Rev. W. Sidgreaves, S.J.*)

In our last report we had the satisfaction of acknowledging the kind permission of the late Postmaster-General to re-erect our radiotelegraphic apparatus. Now we have to express our regret that the Military Authorities have requested the suppression of the installation. We have pressed our claim to an exception in our favour from the general policy against private wireless installations, but without avail.

The meteorological, magnetic, and seismological observations have been carried on as usual.

The solar surface has been observed on 215 days, and 211 drawings on 208 days have been added to our collection. Of these 183 are complete, as showing both the spots and the faculæ, and 25 are complete for all spots, but wanting the faculæ. On 4 days notes with rough sketches of the spots were made. On 2 days only the Sun's surface was found to be free from spots. The mean disc-area of the spots (in units 1/500th of the visible surface) for the year was 4·52, which is almost identical with the value 4·51 for 1915. The drawings during the summer months were made by Mr. W. M'Keon, who paid particular attention to the accurate delineation of the faculæ. Twenty-nine of such draw-

ings, when the weather conditions were particularly favourable, are of excellent quality. They range between the dates May 28 and September 24, and it would be interesting to compare them with spectro-heliograms in H_a and K_3 light. A new light and rigid metal projection apparatus, constructed of an aluminium collar and bicycle rods, designed and made by Mr. G. J. Gibbs, was fitted to the equatorial at the beginning of the year.

The spectra of a few spots were photographed, in the region C – D, with the large grating spectrograph, and a few visual observations were also obtained. These observations confirm the essential permanence of the sun-spot spectrum since the year 1882.

Owing to want of assistance, due to the war, work with the Whitelow prismatic camera has been in abeyance; but, with the Thorp prism equatorial, spectra have been secured of *o* Ceti at two maxima, *α* Orionis, *α* Canis Minoris, *α* Leonis, the Nebula in Orion, and of the planets Mars and Saturn.

Our Belgian guest Dr. Henroteau left us at the beginning of the year to take up a position at the Ann Arbor Observatory of the University of Michigan.

Wolsingham Observatory (*Rev. T. E. Espin's*).

The examination of stars in the selected zones has been continued during the year with the 24-inch Calver reflector, and particulars of the new double stars detected have been communicated to the Society, together with a list of micrometrical measures of miscellaneous double stars already known, but of which there were few or no measures.

Mr. A. M. Newbegin's Observatory, Wallington, Surrey.

Observations of the Sun during 1916 were hindered in the early part of the year by war work and throughout the whole of the year by very unfavourable weather. The results are given in tabular form:—

Number of observations = 100.
„ „ prominences = 1255.
Daily average = 12·55.

Distribution:—

Prominences on N. hemisphere = 641.
„ S. „ = 614.
„ E. limb = 661.
„ W. „ = 594.
Number of prominences under 30″ in height = 281.

Metallic prominences have been observed on 51 days, and at Prof. A. Fowler's suggestion an attempt has been made to classify them under three heads. It is too early to discuss this idea at

present, but there is no doubt of the differences in these metallic outbursts.

The prominences as a whole have shown greater strength than in 1915, not only in density, but in profile area; this, together with the slightly increased daily average, shows the upward tendency of activity very clearly. Apparently the activity has advanced to the northern hemisphere once more, in accordance with previous experience.

Many very fine outbursts have been observed, one on Nov. 17 attaining a height of 360″. It was, however, of quite short duration.

The 5-inch Cooke astrographic lens lent by Mr. Percy Morris has been in use on many nights during the year.

Mr. G. J. Newbegin's Observatory, Lyndale, Sutton, Surrey.

Owing to the very cloudy conditions of the year 1916 only 63 solar observations for prominences were made. By these observations 522 prominences were observed and noted down. A mean daily average of 8·3 was thus obtained.

The position of prominences has now become more northerly though not excessively so, but indicating a movement in that direction.

The planet Venus was a very prominent object in the spring months, and was well observed on many occasions. Later in the year came Jupiter and Saturn, the rings of the latter having appreciably commenced closing again.

Rousdon Observatory, Devon.
(*Sir Wilfred Peek's; Mr. C. Grover, Observer in charge.*)

The building is kept in good repair and the exterior was repainted in the spring. The equatorial is in perfect working order. Weather has been very changeable. April, May, and November were the best observing months, at other times conditions were so bad as seriously to interfere with the continuity so desirable in Variable Star work. Observations were made on 131 nights. Observations of the long-period variable stars have been continued on the same lines as in former years, and 402 magnitudes were determined, making a total of 13,269 magnitudes during the 31 years this work has been in progress. 485 maxima and 348 minima have been observed. The light curves of many of these stars show large and well-marked irregularities, with a difference in light at maxima and minima of fully two magnitudes; the periods also show wide differences, and the dates of maxima and minima very rarely agree with the predictions.

Observations of stars with the transit instrument are frequently taken for regulating the sidereal clock. The usual meteorological observations have also been regularly continued.

The Rev. T. E. R. Phillips's Observatory, Headley, Epsom, Surrey.

At the beginning of the year the Observatory was undergoing removal from Ashtead to Headley Rectory. The Coleman refractor belonging to the Society was dismounted and re-erected by Messrs. Cooke & Sons, the original observatory from Dover being again utilised, with the addition of a small transit house. A new observatory with 17 ft. 6 in. dome was built to cover the 12¼-inch Calver equatorial. This is a good deal larger than is required for this instrument, but it is hoped that a reflector of greater aperture may eventually be installed. The meteorological instruments were also re-established and were in use by the end of the first week in January. The telescopes were not in full working order till the end of February.

The sidereal clock in the Coleman observatory at first gave a good deal of trouble. It was found that when the cord carrying the weight attained the same length as the pendulum, the weight took up the vibration, and the rate of the clock was altered by a considerable amount. A much firmer support of masonry was therefore erected and the trouble largely removed, but it may be found necessary to carry the weight outside the clock to eliminate it entirely.

The Observatory is on high ground about 575 ft. above sea level, and the increased altitude appears to make a perceptible difference in the general character of the seeing. Mist is sometimes experienced in the winter months from low-lying clouds when the valleys are free from fog, but it seems that a larger proportion of the clear nights give good definition. At times the seeing was astonishingly good, and on the whole the experience of the first year is most encouraging.

As regards the programme of work, the Coleman equatorial was again employed in the measurement of double stars, and both instruments in the observation of Mars, Jupiter, and comets. An investigation with the reflector of the colour and visual magnitude of a number of stars within 25° of the pole which show a considerable discrepancy between the B.D. and photographic magnitudes is also in progress.

The main work of the year, however, has been the study of the light curves of 80 long-period variables. These have been analysed harmonically, and a discussion of the results has been communicated to the British Astronomical Association in a Presidential Address at the Annual Meeting in October. It was found on reducing the phases of the first three harmonics to the maximum of the first as reference point, and plotting those of the second and third as abscissæ and ordinates, that with very few exceptions the stars fall into two separate groups. These groups are distinguished not only by the peculiar relationships of their harmonics, but also in some degree by differences in range, brightness, period, and coefficients.

A study has also been made of the oscillations of the maximum of R. Ursæ Majoris, and the results are set forth in the same address.

Mr Reynolds' Observatory, Harborne, Birmingham.

Owing to causes connected with the war, very little work has been done with the 28-inch reflector during the year. A good series of photographs of Jupiter were, however, secured in the autumn of 1916, which show considerable detail. The methods adopted were the same as at the previous opposition, and transparencies of the photographs will be presented to the Society.

Mr. F. Sargent's Observatory, Eastville, Bristol.

The usual planetary observations have been continued, the chief object of study being Jupiter. For the present opposition, observation was commenced during the early hours of July 8, since when the planet has been observed on every favourable occasion, and numerous transits of surface markings timed.

Adverse weather conditions have reduced the number of observing nights, nevertheless the transit total of the previous opposition has been already far exceeded, and interesting results may be anticipated.

An excellent filar micrometer by Cooke of York has been added to the 5-inch refractor, and, within the limits of the equipment, a beginning has been made at double-star measuring.

Sweeping for comets has not been neglected, and will be continued.

Early in the year the mirror of the 10½-inch reflector was refigured, with excellent results.

Mr. W. H. Steavenson's Observatory, West Norwood.

During the earlier part of the year the three comets, Taylor, Mellish, and Neujmin were regularly observed. The last named exhibited a marked fluctuation in brightness at the end of April.

The examination of Struve's pairs of equal magnitude, begun in 1915, was continued with the 15-inch reflector in 1916. Several cases were met with in which the magnitudes are now considerably unequal.

Several multiple stars were regularly observed for variability, notably the system of ϵ Lyræ, and a faint quadruplet in Pegasus, which, falling in the Oxford astrographic zone, was suggested by Prof. Turner for examination.

During April estimates of the magnitudes of 97 of the brightest

stars in the cluster N.G.C. 2632 (Præsepe) were made with the 15-inch. The results have been communicated to the B.A.A.

Barnard's proper motion star was observed several times during the summer with a view to determining its visual magnitude.

Observations of Nova Persei, made in the autumn, showed that the star was still variable, though less so than in 1915. The total range of brightness was 0·6 mag., the average magnitude being about 13·4. To averted vision the Nova appeared to be surrounded by a nebulous glow, 10″ or 15″ in diameter. This was not noticed in 1915.

Helwân Observatory, Ministry of Public Works, Egypt.
(*Superintendent, Mr. H. Knox-Shaw.*)

Time-Service.—The time-service has been maintained as usual.

Reynolds Reflector.—The telescope was used on 93 nights during the year, and 100 plates were exposed.

30 plates on the variable nebula, N.G.C. 6729.
44 „ „ 40 other nebula.
8 „ „ J VIII.
12 „ „ stars of large proper motion.
5 miscellaneous plates.

In addition, four photographs of type A stars were taken with the prismatic camera.

A set of 20 lantern slides of the variable nebula has been presented to the Society, and they were shown at the June meeting of the British Astronomical Association. The plates taken of this nebula in 1916 show nothing strikingly new. They confirm the complexity of the character of the variation of the nebula and R Coronæ.

Solar Radiation.—The programme for 1915 was continued, and complete observations were taken on 143 days during the year. It has not been possible to discuss the 1915 observations yet, but they seem to confirm the results obtained from those of 1914.

General.—Bulletins 17 and 18 were published during the year, the former containing a discussion of the observations of solar radiation made during 1914, and the latter positions of J VIII from photographs taken at the oppositions of 1913 and 1914. A short note was communicated to the Society on the variable nebula N.G.C. 6729. During the second half of the year the Superintendent was working a large part of his time at the Physical Service, and thus little work other than that of a routine character has been done. While he was on leave in the summer, his place was taken by Mr. E. W. Bliss. The same meteorological, seismological, and magnetic observations were made as in 1915.

Nizamiah Observatory, Hyderabad, Deccan.
(*Director, Mr. R. J. Pocock.*)

At the beginning of the year the astrographic work was temporarily in abeyance owing to the fact that plates ordered from England some time previously were lost with the S.S. *Persia*. A further batch of plates was lost with the S.S. *Maloja*. The first two months of the year were therefore mainly devoted to measuring plates taken at the University Observatory, Oxford, with a view to the determination of proper motions; the results of this investigation have already been communicated to the Society.

Apart from this delay, astrographic work has continued steadily throughout the year.

The total number of plates measured during the year is 211, containing 70,278 stars, which with those measured previously makes a total of 322 plates, containing 115,233 stars.

Zone $-17°$ is now complete, and the copy for press of the whole is in the hands of the printers. The 180 plates in this zone contain 63,439 stars, an average of 362 stars per plate. The printing of this zone was seriously interfered with by the fire at Messrs. Neill & Co.'s works in Edinburgh, in which about 80 pages of corrected proofs were destroyed; by the end of the year, however, 166 pages of first proof had been read and returned to the printers, and in the absence of any further delays this volume should be ready for distribution during 1917.

In Zone $-18°$, 153 satisfactory plates have been secured, of which 142, containing 51,794 stars, have been measured, reduced, and copied for press; it is hoped that the printing of this zone may be started very shortly.

In Zone $-19°$ the whole of the necessary tables and standard co-ordinates have been completed, and 53 satisfactory plates secured.

In Zone $-20°$, 14 satisfactory plates have been secured, but no measures had been made of plates in Zones $-19°$, $-20°$ up to the end of 1916.

The four lenses lent to the Kodaikánal Observatory are still retained at Kodaikánal on loan.

Kodaikánal and Madras Observatories.
(*Director, Mr. John Evershed.*)

Dr. Royds was in charge of the Observatory from the beginning of the year until November 23, the Director being on special duty in Kashmir.

The year has been a favourable one for solar work, and visual observations of the Sun's limb with the 6-inch telescope and large grating spectroscope were made on 315 days, while sun-spots were recorded on 342 days.

Cambridge Spectroheliograph.—Very satisfactory photographs

were obtained throughout the year whenever the definition was good; that is, usually before 8.30 a.m. Disc spectroheliograms were obtained on 329 days and prominence plates on 346 days, including plates taken at Srinagar. All the prominence plates were measured.

Grating Spectroheliograph.—Photographs of the Sun in Hα light were obtained on 258 days. The plates for this work are now sensitised at the Observatory by the photographic assistant, and are superior to commercial red sensitive plates. A special apparatus has been constructed for drying the plates after sensitising. The number of absorption markings due to dense prominences on the Sun's disc has increased largely, and some very remarkable forms were photographed in April.

Photoheliograph.—This was dismantled in 1915 for work in Kashmir, and no direct solar photographs were obtained at Kodaikánal in 1916. The series of 8-inch photographs will be resumed in 1917. At Srinagar a series of 8-inch photographs was obtained during the earlier months of 1916. In May the instrument was modified to give a larger scale, and during the summer sun-spot regions were photographed on a scale of 15 inches to the diameter.

Grating Spectrograph.—Dr. Royds has employed this instrument for studying the solar displacements at the centre of the disc, and at the limb, of the nickel and titanium lines, using these metals in the electric arc for comparison with the solar lines. The plates obtained have all been measured and reduced, and the results were ready for publication at the close of the year. In general these results confirm those obtained with iron, and indicate a low pressure in the reversing layer, and a descending movement of the gases at the centre of the disc. Spectrum plates were also obtained in continuation of the research on the displacements in the Sun of lines which are greatly shifted at the negative pole of the arc.

During December the spectrograph was modified for the purpose of photographing the spectrum of Venus. In this work the 15-inch Hyderabad lens, after its return from Kashmir, was used to great advantage, and spectra were secured of the planet having a dispersion of 0·7 A. per millimetre. Measures of the plates by the positive on negative method will probably yield a fair value of the solar parallax, but the main purpose is the determination of the wave-lengths of some of the solar lines on the side of the Sun turned 90 degrees or more from the direction of the earth.

The research on the change of wave-length of the iron lines between the centre of the Sun's disc and the limb has been completed and published (Kodaikánal Observatory Bulletin No. xlix.), and the sun-spot radial motion plates obtained in 1915 have been measured and the results published in Kodaikánal Observatory Bulletin No. xli.

A number of measures of solar and arc spectra has also been accomplished for the purpose of testing the anomalous dispersion theory. The results show fairly conclusively that anomalous

dispersion is not an effective agent in displacing solar lines (*Observatory*, vol. xxxix. 432).

Kashmir Expedition.—The purpose of this expedition not having been fully accomplished by March 1916 owing to very abnormal weather conditions, the Government of India sanctioned an extension of the work for a further period of seven months at the request of Dr. Walker. The two assistants, Messrs. Sitarama Aiyar and Krishna Aiyar, who had rendered such excellent service during the earlier period, returned to Kodaikánal in March, and the Director and Mrs. Evershed continued the work at Srinagar until November 1st.

The results obtained during the summer of 1916 amply confirmed the original estimates of the excellence of the climate for solar work. During the winter and early spring, as also in late autumn, the conditions do not differ very appreciably from those in other localities, the definition being good in the morning and evening and poor at midday. In May a marked improvement occurs in the midday seeing, which appears to coincide with the flooding of the paddy fields. In the summer months good definition throughout the day is the rule, and superlative definition is of quite frequent occurrence. Very beautiful solar photographs were secured in July and in August under temperature conditions ranging from 80° to over 90° in the shade.

The two principal factors which it is believed conduce to the good definition are the absence of disturbing winds excluded by the surrounding wall of high mountains, and the very large areas of wet cultivation which in summer greatly reduce the heating effect of the Sun on the soil.

Publications.—Four Bulletins were issued during the year, Nos. xlix. to lii.

At Madras the time-service was maintained as in former years.

The Dominion Observatory, Ottawa.

Geophysics.—This branch of the activities of the Observatory comprises seismology, terrestrial magnetism, and gravity. The equipment of the three divisions consists of the same instruments as reported in the preceding year.

Twenty-two bulletins of earthquakes recorded at the Observatory were issued during the calendar year 1916, representing 104 seismic disturbances. During the preceding year only 81 earthquakes were recorded, so that 1916 shows an increase of 23. There was issued early in the year in the *Publications of the Dominion Observatory*, No. 2, vol. iii., Seismological Tables of sixty-one pages and two diagrams, by means of which seismograms can be more readily interpreted and the location of the epicentre is facilitated. The study of microseisms, which are often a disturbing factor in reading seismic records, was continued in connection with

the records of the undagraph exposed to the action of the waves of the Atlantic at Chebucto Head, near Halifax, Nova Scotia.

The magnetic survey—declination, inclination, and intensity—of Canada was continued and 55 stations were occupied, making a total now of 479 stations distributed across Canada from the Atlantic to the Pacific. Quite a number are "repeat" stations.

The gravity survey of Canada was suspended for the year. There are now 45 gravity stations in Canada between the Atlantic and Pacific. The observations are all standardised with those of Washington, and through the latter with the European work, by observations with the Observatory pendulums on several occasions in Washington.

The reduction of the observations follows closely the method adopted by the U.S. Coast and Geodetic Survey.

Meridian Observations.—Observations with the meridian circle were obtained on 103 nights: they were devoted in part to determinations of clock error for longitude work and the purposes of the time-service, and in part to a continuation of work on the list of latitude stars mentioned in previous reports. Two observers were engaged throughout the year, and two others for shorter periods. During the last eight months of the year a modification of Hough's printing chronograph was employed for the registration of transits, and has worked very satisfactorily.

Four Laplace stations were established, two in British Columbia, one in north-western Ontario, and one in New Brunswick. The longitudes of three of these were determined by the ordinary telegraphic method, that of the fourth by wireless telegraphy: at three of the stations the azimuth of one of the lines of the geodetic triangulation was measured with an alt-azimuth, at the fourth a meridian mark was established and its azimuth determined by observations with the astronomical transit used for the longitude.

A new list of 519 stars has been prepared for use in field longitude operations. It includes stars between 10° north declination and the pole, and is somewhat more extended than those found in the national ephemerides, especially in the case of stars of comparatively high declination culminating during the summer months. The stars were selected from Boss's Preliminary General Catalogue, and the right ascensions and proper motions of the weaker ones strengthened by the inclusion of available data from observations at Ottawa and at Greenwich, after the application of suitable systematic corrections to reduce the observations to the system of Boss.

The time-service has been maintained as in previous years Nearly 300 electrically driven clocks, including two tower clocks, are operated in the various Government buildings by means of several secondary master-clocks continuously synchronised from the Observatory. In addition, relays beating seconds are maintained in several offices in the city, time-signals are sent out by telegraph and telephone, and the time is recorded on the various seismographs at the Observatory.

Astrophysics.—During the past year the 15-inch refractor has been employed, as hitherto, almost entirely in determining the radial velocities of spectroscopic binary systems with a view to the determination of the elements of their orbits.

During the calendar year 1916 a total of 506 plates was obtained on 162 nights, the average photographic magnitude of the stars observed being 5·6. This somewhat smaller number of spectra obtained than previously is due partly to the absence of one of the observers on military duty and partly to the scarcity and faintness of suitable binaries for observation. The orbits of six binaries—14 Aurigæ, x Aurigæ, 125 Tauri, Boss 2484, Boss 6142, and 2 Sagittæ were completed during the year. Of these x Aurigæ is of special interest as having an unusually long period, 655 days, for a B type star, and because of the peculiar behaviour of the H and K lines of calcium.

A determination of the solar motion from the radial velocities of the spiral nebulæ giving a value of about 600 kms. per second is of interest as indicating the possibility of an enormous velocity of our stellar system.

A table for the conversion of right ascensions and declinations into longitudes and latitudes has been constructed and is ready for publication. The interval in R.A. is four minutes of time and in Dec. 1 degree, while the longitudes and latitudes are given to the nearest minute. This table will facilitate the reduction of stellar radial velocities to the Sun and will doubtless find other applications.

Extra-focal photometric observations are being carried on with the six-inch doublet, testing the spectroscopic binaries whose orbits have been determined here for variation in magnitude, but as yet without positive result. Photometric work by the same method for the purpose of improving the light curve of δ Libræ is also being pursued, and the methods for testing and developing the plates have been improved.

Observations with the cœlostat telescope on the solar rotation and allied problems have been continued during the year, and four papers bearing on this work have been published. The first on a variation in the solar rotation showed strong evidences of a cyclic change in the rate of about eight per cent. taking place in about a month, while the last, on the effect of haze on the solar rotation, showed that some of the observed changes found here and elsewhere might be due to the presence of a varying amount of haze in the terrestrial atmosphere. Work on this latter phase of the question is being continued to determine to how great an extent haze can effect solar rotation measures, and to what degree past measures have been influenced.

The 72-inch reflecting telescope, the condition of which was reported upon last year, has made satisfactory progress and is now nearly completed.

The structural work and operating mechanism of the dome arrived at Victoria in April, was erected during May and June,

covered by its double sheet-metal casing during August and September, and placed in complete operating order in October. The mounting of the telescope was completed in April, but shipment was delayed until the dome was sufficiently advanced in July, and it arrived at Victoria about the middle of August. Erection began early in September and was completed in about six weeks. Both telescope and dome are splendid examples of engineering skill, operate to perfection, and reflect great credit on the makers, the Warner & Swasey Co., of Cleveland.

The main mirror of the telescope is now in the final stages of parabolizing, and is expected to be completed early in 1917. As the observatory building and telescope are all ready for the installation of the optical parts, actual observing with the instrument should be possible in the Spring.

Adelaide Observatory, South Australia.
(Director, Mr. G. F. Dodwell, Government Astronomer.)

Meridian and Time-Service.—The transit-circle telescope was used throughout the year for the observation of the intermediate standard stars of the Sydney zone ($-52°$ to $-64°$). The observations were reduced from day to day by the aid of graphic reductions. The construction of R.A. graphs was greatly facilitated by the use of new differential tables due to Professor W. E. Cooke of Sydney Observatory. Fundamental stars in the zone were used for the daily time-service. The time-ball at the semaphore was dropped at 1 p.m. daily, except on Sundays. On occasions when telegraphic communication was temporarily interrupted, the time-ball was dropped by hand by the signalman on a signal given through the telephone from the Observatory. For this purpose a telephone and push-button were installed at the Time-Ball Station close to the releasing trigger. A return signal apparatus which had also been installed showed that the internal lag of the mechanism was 0·3 second. The ordinary system of distributing the time to the country telegraph stations and various Government Departments was continued. The transmission of time-signals to the Adelaide Radiotelegraphic Station and thence by wireless to shipping has been continued, the signals being those adopted by the International Convention. They were emitted throughout the year at midday and midnight, Adelaide standard time.

Field Work. — Latitude, Longitude, and Magnetic Stations were established at Bordertown, Naracoorte, Wilmington, Melrose, Booleroo Centre, Port Pirie, and Mount Brown. For the magnetic work a magnetometer outfit, lent by the Carnegie Institution, and dip circle lent by the Sydney Observatory, were used. Professor Kerr Grant of the Adelaide University, and one of his research assistants, Mr. R. S. Burdon, co-operated in the work at Bordertown and Naracoorte. For latitude and longitude work the al-

mucantar method of observing was used, and longitude signals from the Adelaide Observatory *via* the Radio Station were received from a portable wireless receiving outfit. A permanent mark at the site of observations and concrete block to indicate the meridian are being established at each of these stations.

Seismology. — The Milne Seismograph was continuously at work during the year, and the tabulated records were sent as usual to the Shide Observatory, Isle of Wight.

Miscellaneous. — The Board of Visitors held their second Annual Meeting at the Observatory on November 17.

Mr. C. A. Maddern, a member of the Staff, has been at the front with the Australian Imperial Forces since the beginning of the year. His work at the Observatory is being carried out *pro tem.* by Mr. W. R. Blackman.

The annular eclipse of the Sun on July 30 was observed under ideal weather conditions. A series of photographs was taken with a photographic attachment fixed at the eye end of the 8-inch Cooke equatorial telescope. These photographs were used by Professor Grant in connection with actinic measurements made at the Adelaide University during the eclipse. A report of this work, with copies of photographs, etc., was sent to the Royal Astronomical Society. The equatorial telescope was used principally in connection with the regular Friday night visits by the public, and also on certain evenings by members of the S.A. Astronomical Society for variable star and other observations.

Perth Observatory, Western Australia.
(*Director, Mr. H. B. Curlewis, Acting Government Astronomer.*)

Meridian Observations.—Throughout the year work on the Transit-Circle was confined almost solely to time determinations, 197 nights being thus employed.

Astrographic Catalogue. -The work is proceeding steadily, and only zone 33° and a portion of 35° remain to be finished. With regard to the printing, progress is slow, but, so far as can be foreseen, no stoppage is likely to occur. The four volumes of zone 36° and those of 37°, which should be out of the printer's hands shortly, will not be distributed till after the war, as at present there is no guarantee of their safe transmission.

Seismology.—With the exception of a few hours lost by the failure of the light, the record of the Milne Seismograph was continuous. Nineteen distinct earthquakes were recorded, of which seven had semi-amplitudes of 10 or more millimetres, while the remaining thirteen were small, the semi-amplitudes being under five. Distinct tremors numbered nine, while faint tremors or microseisms were innumerable. A very fine record of the Rabaul earthquake of January 1 was received, and also one on 13th of the same month.

During the latter half of the year local earth tremors, of some severity, were reported from various parts of the State.

Tidal.—During the year the predicted tide curves for Port Hedland for 1917, based on the constants derived from the analysis of the 1913 hourly records, were received from the Superintendent of the United States Geodetic and Survey Department. The figures extracted from these curves were published and distributed towards the end of the year. Beyond this the tidal work remains in abeyance, which is to be regretted. It is to be hoped that the work will be re-started before long, for a more exact knowledge of the tides, especially on the N.W. and N. coasts of Australia, is very desirable.

Time-Service.—The time-ball at Fremantle only failed on three occasions. This is a very decided improvement on all previous years, and speaks well for the attention bestowed upon the line by the Telegraph Department. The automatic check upon the time of ball drop is still maintained, and with few exceptions the error was within one-tenth of a second. On June 30 the ball was two seconds slow, owing to the current for regulating the Mean Time Clock being switched on in the wrong direction. The method of disseminating the time throughout the State remains the same as in the past, and was carried out satisfactorily.*

The Observatory is not yet connected with the Wireless Station at Applecross, and therefore time-signals cannot be sent from there. Repeated efforts have been made to bring this about.

Popular, Educational, and Miscellaneous.—Day and night visitors were even more numerous than usual, nearly every Tuesday afternoon being engaged and 109 evenings. The total number of people visiting the institution on these 109 nights was 1270, which constitutes a record, and proves that public interest in the Observatory and in Astronomy is increasing.

A number of lectures were given during the year, and the usual information supplied to the Press and private correspondents.

The Western Australian Astronomical Society, under the ægis of the Observatory, still flourishes, and at the end of the year published a useful and instructive journal.

Union Observatory, Johannesburg.
(*Union Astronomer, Mr. R. T. A. Innes.*)

Instrumental Equipment.—This remains unchanged.

9-inch Refractor.—Measurements of double stars have been continued upon the usual lines, and the phenomena of Jupiter's Galilean Satellites have been regularly observed. Miscellaneous observations were also made.

* An apparatus was installed during the year, by means of which the second-beats of the Mean Time Clock can be transmitted automatically by telephone.

2⅝-inch Talcott Telescope.—This has been used for the Time-Service. The observations for variation of latitude 1910 March–1914 December have now all been reduced and the final results have been sent to press.

Franklin-Adams Star Camera and Twin-Telescope.—These two instruments have been in partial use for the observation of minor planets, variable stars, etc.

Time-Service, Meteorological and Seismological Observations.—These have been continued without change. The shocks due to past mining operations have decreased from 893 in 1915 to 414 in 1916, and both public anxiety and interest in them have abated, although several shocks have been strong enough to rattle the whole town.

Staff.—Mr. Van der Spuy, who has left the observatory, has been awarded the Military Cross. Mr. Wood volunteered and was accepted in April, and Mr. Johnson in January, for service in German East Africa, and they have not yet returned. Mr. Worssell volunteered both in England and here, but was rejected on account of his myopia. Mr. Worssell and the two lady assistants have maintained the routine work, and all reductions are up to date. The state of the staff was such that in 1916 little besides routine work could be undertaken. Mr. Worssell has, however, photographed some minor planets, and observed southern variable stars and some occultations.

Observatory Circulars.—Nos. 33 to 35 were actually distributed in 1916, and No. 36 is in the hands of the Government printers. No. 33 contains the fifth series of Double Star measures, lunar occultations of stars in 1915, and some miscellaneous observations. No. 34 contains the observations of Jupiter's Galilean Satellites during the opposition of 1915, and here it might be added that a complete comparison with Sampson's Tables is now available; this number also included observations of minor planets and miscellaneous matter. No. 35 contains the result of a blink examination of pairs of plates loaned by the Astronomer Royal for the determination of proper motions, and marks the beginning of a systematic piece of work which has been continued throughout the year and is still in progress. The Astronomer Royal has proposed that we should examine here the whole zone $+66°$ as far as any suitable pairs of plates are available, and other pairs to the North Pole of any very good pairs of plates. The zone $+66°$ is now completed to 18h. 36m. Three further excellent pairs of plates from H.M. Astronomer at the Cape have been examined, and the results are ready for publication: one of the regions of these plates had previously been measured by Professor Kapteyn, and the comparison of the two results is instructive. The Director of the Melbourne Observatory has already sent some selected pairs of plates, and will be sending more. It has been agreed with the Director of the Sydney Observatory that the whole of the Sydney zone shall be blinked here, and a start has already been made. Hence there is already on hand a number of unpublished proper motions. A list of those

exceeding half a second a year and previously unpublished is given here:—

				Centennial Proper Motion.	
B. D. +66° 34′				178″·6	
	m	h	m		
Anon.	13	13	50	+66 7	57·5	
,,	10·4	0	36	−53 2	88·6	
,,	11	6	11	−65 9	82·0	
,,	10	11	39	−64 8	269·0	
C.P.D. −65° 1714:					55·0	: = Double star.

A good deal of work with the blink microscope has been done on variables near η Argûs and near Corona Australis; and in the latter region over 150 new variables have been found, and the hard work of looking them up on our 28 plates of the region is half completed.

Miscellaneous.—Some experimental work on the proposed charts of the southern sky was done, and the Government printer has imported a finer screen. The original idea was to reproduce on the scale of $1' = 1^{mm}$ (carte du ciel scale), but at present a scale of $1° = 36^{mm}$ is in favour; this latter is practically the scale of the Wolf Palisa charts.

Desk work has included an algebraical or literal development of the perturbative functions required in the theory of Jupiter and Saturn, and some attempts to produce eclipse tables for Jupiter's Satellites on the lines of Damoiseau's Tables, but with modern constants derived from Sampson's and de Sitter's work.

Lovedale Observatory, South Africa.
(*Dr. Alexander W. Roberts.*)

During the year 1916 the work done at this observatory has been mainly the reduction of past observations.

In the light curves of a great majority of stars, both of long-period and of short-period variation, a definite secular change has been made manifest, and this has caused the work of reduction to be more onerous than was at first anticipated.

In addition to the reduction of past observations, there was also carried on the regular observation of stars whose variation indicated secular change of period. The number of observations made were:

Short-period stars	1120
Long-period stars	1200
	2320

Further, there was carried on during the year a systematic

comparison of southern fields with northern fields. The photometer used was one of very simple construction, viz. two mirrors capable of being inclined at any angle, and moving on universal bearings.

Eight settings, in which the position of the mirrors and of the observer were so allied as to eliminate personal and instrumental errors, gave a relative error of $\pm 0^{m}\cdot 03$ in the comparison of any two fields.

Notes on some Points connected with the Recent Progress of Astronomy.

Discovery of Minor Planets in 1916.

Sixty-four minor planets were discovered or first announced in 1916, as follows:—

Letter and Number.	Date.	Discoverer.	Letter and Number.	Date.	Discoverer.	Letter and Number.	Date.	Discoverer.
	1904.			1916.			1916.	
a	July 7	W	ZH 824	Apr. 1	W	AG	Sept. 23	W
	1915.		ZJ	2	,,	AH	24	,,
a	Feb. 16	T	ZL 825	3	,,	AJ	24	,,
b	Sept. 12	,,	ZM	Mar. 31	,,	AK	25	,,
c	14	,,	ZO 826	Apr. 28	,,	AL	Oct. 1	,,
d	Dec. 8	,,	ZP	28	,,	AM	1	,,
e	Sept. 10	Pe	ZQ	30	,,	AN	Sept. 30	T
	1916.		ZR	May 6	,,	AO	30	,,
YT 814	Jan. 2	N	ZS	July 28	Pe	AP	Oct. 1	R
YU 815	Feb. 2	W	ZT	Aug. 1	,,	AQ	18	T
YV 816	8	,,	ZU	1	,,	AR	17	,,
YW 817	6	,,	ZV	9	,,	AS	Nov. 16	W
YX	1	T	ZW	29	Pa	AT	26	G
YY	19	,,	ZX	29	,,	AU	29	,,
YZ 818	21	W	ZY	31	W	AV	29	T
ZA 819	Mar. 3	,,	ZZ	Sept. 3	,,	AW	Dec. 24	W
ZB 820	30	,,	AA	20	,,	AX	27	,,
ZC 821	31	,,	AB	20	,,	AY	27	,,
ZD 822	31	,	AC	20	,,	AZ	27	,,
ZE	31	,,	AD	20	,,	*a*	May 26	S
ZF	31	,,	AE	23	,,	*b*	Oct. 2	,,
ZG 823	31	,,	AF	23	,,	*c*	Dec. 16	M

Another minor planet is announced as discovered last year by Peters at Washington, 1916 April 10.

The letters stand for :—

W = Professor M. Wolf, Königstuhl, Heidelberg.
T = Dr. Thiele, Bergedorf, Hamburg.
G = Herr Gyllenberg, Bergedorf, Hamburg.
Pa = Dr. Palisa, Vienna.
R = Herr Rheden, Vienna.
N = Mr. G. Neujmin, Simeis, Crimea.
Pe = Mr. G. H. Peters, Washington.
S = M. Sy, Algiers.
M = Dr. Metcalf, Winchester, Mass.

Of the planets in last year's Report, the identity of XU with 193 Ambrosia is confirmed; YC = 239 Adrastea, YQ = 1911 LG = 1894 AW = 604 Tecmessa. The following have received permanent numbers: 1901 GY (seen again 1908, 1915) 808, 1915 XP 809, XQ 810, XR 811, XV 812 (= 1902 KC), YR 813. 1915 YL was probably a comet.

Planets 753, 797 have been named Tiflis, Montana, respectively. Planet 814 is identical with 1907 ZR, 817 with 1908 CP, 823 with 1913 *a*, 824 with 1913 TB. An object (ZK) found by Wolf on 1916 Apr. 3 proved to be a comet (see Comet Report). ZN, found on Apr. 28, is 271 Penthesilea.

The motion of planet 1916 *c* (Metcalf) indicated that it was near the Earth, but the orbit is not yet to hand. The magnitude was $13\frac{1}{2}$, so it must be an exceedingly minute body.

It will be seen that the second double alphabet for denoting new discoveries has now been completed, and the third commenced. Each of them contains 625 combinations, the letter I being omitted. The first extended from 1894 to 1907, the second from 1907 to 1916, indicating a somewhat higher rate of discovery in the latter period. It is necessary to prefix the year of discovery to the letters to avoid confusion.

Besides the 826 numbered planets, 19 more have been observed sufficiently for the determination of elliptical orbits, and 51 more for circular orbits, so that orbits of some sort have been found for 896 planets.

Of the first 520 planets there are only 13 that must be regarded as lost, having been seen at no opposition since that of discovery. The lost planets are 132, 155, 220, 285, 323, 330, 392, 396, 400, 452, 463, 473, 515.

Mr. Dinsmore Alter gives a search ephemeris for 132 Æthra, on the assumption that it is identical with an object photographed at Flagstaff 1913 June 10. On this assumption the magnitude in 1917 April would be 9·9, the declination 44° south (Lick Observatory Bulletin, 285).

433 Eros was in perihelion early in December 1916, and fairly bright, though it was several months before opposition. Mr. Leon Campbell, using the 15-inch equatorial at Harvard Observatory, noted a light variation of 0·4 magnitude on December 29; minimum light occurred $29^{d}\ 21^{h}$ G.M.T.

Professor H. C. Plummer (*M.N.*, vol. lxxvi. 5) and Mr. S. G. Barton (*Astr. Journ.*, 702) have examined the statistics of the orbits of minor planets. The most striking feature is the grouping of perihelia near that of Jupiter. There are three times as many perihelia within 10° of Jupiter's perihelion as within 10° of its aphelion. The average eccentricity is 0·12. Professor Plummer suggests that when material is insufficient for determining an elliptical orbit it would be better to assume an ellipse with perihelion in the direction of Jupiter's and eccentricity 0·12, than to assume the orbit a circle.

Mr. Barton finds that g (the stellar magnitude of a planet at a certain fixed distance from Sun and Earth) averages $8^{m}\cdot38$ for the first 400 planets, and $9^{m}\cdot32$ for the second 400. The corresponding average values of μ (the mean daily motion) are 793″, 765″. Since g measures the size of the planet on the assumption of uniform albedo, these figures indicate that the later discoveries are both smaller and more distant than the earlier ones. He also finds a correlation between i and e, indicating that large eccentricities usually go with large inclinations. A. C. D. C.

Discovery of Comets in 1916.

1916 *a*. The first cometary discovery of the year was made by M. Neujmin at Simeis on February 21. The comet was faint throughout, not becoming much brighter than the 11th magnitude. The last observation was made on June 3 at Johannesburg. It proved to be a short-period comet of Jupiter family, with period $5\frac{1}{2}$ years. Its orbit and that of Encke's Comet are almost in the same plane, and have both their foci coincident, which may indicate a former connection between them. Neujmin's Comet appears to have been near Jupiter in 1903.

1916 *b*. This comet was discovered by photography by Professor Wolf at Königstuhl, Heidelberg, on April 3. It was at first taken for a minor planet, and designated ZK. It was subsequently found to have a nebulous envelope, and to be moving in an approximately parabolic orbit. Perihelion will not be passed till 1917 June 16, $14\frac{1}{2}$ months after discovery, an even longer interval than in the case of Delavan's Comet, 1913 *f*. This comet will be well placed for observation next summer, and will probably become a naked-eye object, but its perihelion distance, $1\frac{2}{3}$ units, is too great to give expectation of a very brilliant display. It was followed till the beginning of July, and recovered as a morning star on December 23 by M. Gallo in Mexico, the positions agreeing very closely with those of Crawford's ephemeris, based on the elements printed below.

1916 *c*. This was a photographic observation of Encke's Comet by Professor Wolf at Königstuhl on September 22, one month after aphelion passage. He found it with the aid of an ephemeris prepared by Mr. F. E. Seagrave; the motion between two exposures agreed with that given by the ephemeris. It was of magnitude $16\frac{1}{2}$, and appeared as a very faint nebulous envelope with a small well-

defined central condensation. It was also photographed by Thiele at Bergedorf on November 15, 26, 27 (*Astr. Nach.*, 4870). It will not reach perihelion till 1918 March 25.

1916 *d*. Dr. J. Metcalf announced the discovery of a comet on November 21 on a zodiacal plate taken in the course of his search for minor planets. It was almost exactly in opposition to the Sun. Photographic observations on November 22, November 26 were published, but I understand that they were subsequently withdrawn as erroneous. Professor Wolf published an observation on November 28 of an object which he took to be the comet, but it proved to be the minor planet 368 Haidea. Messrs. Braae and Vinterhansen give the following very uncertain orbit of Metcalf's Comet: T = 1916 Sept. 18·185 G. M. T., $\omega = 94^\circ\ 56'\cdot2$, $\Omega = 237^\circ\ 49'\cdot0$, $i = 18^\circ\ 57'\cdot9$, $\log q = 9\cdot87672$. It distantly resembles the orbit of Biela's Comet.

Besides the above comets, a bright cometary object, with very rapid motion, was seen by Professor Perrine and his assistants at Cordoba on May 4. Dr. Estelle Glancy deduced an approximate orbit, on the assumption that it was a comet. This indicated a very close approach to the Earth (much nearer than the Moon). As the object was not seen again, its character must remain somewhat doubtful.

Mellish's Comet, 1915 *a*, was followed by photography by Professor Thiele at Bergedorf, Hamburg, till 1916 September 25, when it was considerably outside the orbit of Jupiter. Delavan's Comet, 1913 *f*, was followed till nearly the end of 1915. The orbit appears to be hyperbolic, as was pointed out by M. Van Biesbroeck.

Taylor's Comet, 1915 *e*, was observed till 1916 May 2. This comet belongs to the Jupiter family, with a period of $6\frac{1}{8}$ years. Like Mellish's Comet, 1915 *a*, it exhibited the phenomenon of partition of the nucleus. Professor Barnard was the first to detect this on February 9, when the two nuclei were 10″ apart, in P.A. 21°. Calling the northern and southern components N and S, N was at first the fainter. Both had short tails. For a time N continued to get fainter, S became brighter and more condensed; then N brightened and showed strong condensation, while S became diffused and faint; finally it disappeared altogether, leaving N a strongly condensed comet. Professor Barnard gives the following cases of partition of comets:—Biela's Comet, Comet 1860 III., Great Comet of 1882, Brooks 1889 V., Swift 1899, Kopff 1906, Halley's Comet in 1910 May.

The following are the elements of Taylor's, Neujmin's, and Wolf's Comets, referred to the Equinox of 1916·0:—

Comet Computer.	1915 *e* (Taylor) Jeffers, Neubauer.	1916 *a* (Neujmin) Braae.	1916 *b* (Wolf) Crawford, Alter.
T in G. M. T.	1916 Jan. 30·9403	1916 Mar. 11·2350	1917 June 16·4806
ω	354° 49′ 1″·6	193° 43′ 17″·7	120° 37′ 7″·9
Ω	113° 54′ 5″·1	327° 30′ 59″·6	183° 16′ 58″·8
i	15° 31′ 43″·5	10° 39′ 53″·0	25° 40′ 6″·4
$\log q$	0·192540	0·127494	0·226855
Period (years)	6·3662	5·49969	Parabola

The elements of Taylor's Comet show a slight resemblance to those of Daniel's Comet 1909 IV. (period 6·4 years). This comet made a near approach to Jupiter in February 1912, when the elements must have undergone considerable alteration.

Perrine's Periodic Comet (1896 VII.–1909 III.) escaped detection at its return in 1916.

MM. A. Andoyer and B. Jekhowsky in the course of developing a new method of computing perturbations for planets and comets (*Bulletin Astronomique*, 1916 March), incidentally suggest an interesting method of computing preliminary orbits for new comets. It is well known that three complete observations give one equation too many for computing a parabolic orbit. They suggest treating the Sun's mass as a sixth unknown ; the equations can then be satisfied exactly, and there is only one real solution. If the value found for the Sun's mass is near the truth, it indicates that the true orbit is practically parabolic, while an erroneous value of the Sun's mass would generally indicate an elliptical orbit. Even in the latter case the authors demonstrate, from the case of Tuttle's Comet, that the parabola found will suffice to give a tolerable ephemeris for a month or two (assuming that the observations used are good), so that the labour of computing an ephemeris from poorly determined elliptical elements is avoided. They further indicate that by combining their method with that of Leuschner, a cubic equation can be formed, with only one real root, for determining the comet's distance from the Earth.

A. C. D. C.

Solar Activity in 1916.

Sun-spots.—The year 1916 was one of full, but not of exceptional, activity so far as sun-spots are concerned. Quite a considerable number of groups were easily visible to the naked eye, and the complexity of the structure of many groups, as seen in the telescope or on photographs, was a striking feature of the year.

January opened with much the same moderate average of spot activity as shown by 1915 December, but early in February a very fine stream developed in the Southern Hemisphere, and another, slightly smaller, in the Northern. In March the Sun's surface was greatly disturbed, no fewer than four groups being large enough to be seen by the naked eye. This activity continued into April, but somewhat declined in the middle of the month. May was distinguished by several fine groups, much the largest of which formed in the visible hemisphere, and developed into a continuous stream of 14° of solar longitude in extent. June was remarkable for the long successions of spots forming about latitude 15° on both sides of the Equator, giving towards the end of the month a "belted" appearance to the solar disc. This action was much more conspicuous in the Northern Hemisphere, where it was repeated on a minor scale in July, while the southern disturbances died down.

August and September were in general months of solar quiescence, though each had one considerable disturbance. But in October a marked revival set in, and a fine succession of active spots were seen in the Northern Hemisphere from October 4 to 21, followed towards the end of the month by a fine stream in the Southern Hemisphere. November was distinguished rather by widespread and diffuse disturbances than by large concentrated groups, and December, so far as the weather conditions permitted the Sun to be observed, seems to have been a month of moderate activity. On the whole, 1916 seems to have shown a distinct but not a great increase on the sun-spot activity of 1915. E. W. M.

The Prominences.—The mean daily areas of prominences in square minutes of arc, derived from photographic records made at Kodaikánal and at Srinagar, are as follows:—

	North.	South.	Total.
1916 January to June . .	2·06	1·77	3·83
July to December .	1·98	1·65	3·58

The corresponding totals for the year 1915 were, for the first six months 5·27, and for the second six months 5·29. A reduction of area amounting to about 30 per cent. is thus shown.

The mean daily number of prominences recorded during the year is 18·9, a reduction compared with 1915 of under 1 per cent.

The distribution in latitude shows that the diminution of area affects practically the whole Sun, but is especially marked in the south between 20° and 40°. There has been a progressive change during the year in the position of the high latitude zones of activity, which are now approaching the poles. They occupied almost the same position as in the year 1905, and will probably close over the poles during 1917. The northern zone is, however, about 5 degrees ahead of the southern, and this is clearly shown also by the prominences projected on the disc as absorption markings.

The northern hemisphere has shown a greater activity than the southern, not only in mean area but also with regard to metallic prominences and displacements of the hydrogen lines. The northern prominences were also denser than the southern, as indicated by the preponderance of Hα absorption markings in the north.

The distribution east and west of the Sun's axis is interesting, as indicating a return to the condition of eastern preponderance. There is, however, only a slight excess of east over west in prominence areas and numbers, the percentage east being 50·6 and 50·5 respectively, derived from a total of 6129 prominences. Prominences projected on the disc as absorption markings give percentages east of the central meridian as 52·2 for areas and 51·5 for numbers, derived from 2618 prominence markings. D_3 darkenings also preponderate east of the central meridian, and of 489 bright reversals of Hα on the disc, 54·3 per cent. were east. Only fifty-eight metallic prominences were recorded during the year, and

these were more frequent west of the central meridian. 438 displacements of Hα were observed in the chromosphere and prominences, and of these 55 per cent. were on the east limb.

As is usually the case, there was an excess of displacements towards red, although less marked than in former years. The largest displacements were observed on April 7th 4 A. to red, April 11th 5 A. to violet, and on November 6th 4 A. to red.

On May 26 a very complete record was obtained at Kodaikánal and at Srinagar of an eruptive prominence which rose to the extraordinary height of over 18′, or about half a million miles above the chromosphere. Measures of the photographs show the usual accelerating velocity of ascent, and a very remarkable outward motion attaining over 300 km./sec., apparently radiating from a centre situated in the chromosphere. Motion in the line of sight in this prominence did not exceed 140 km./sec.

It is interesting to note that on May 28 a very similar eruption was observed by Buss in the same solar quadrant, and described by him in the *Observatory*, vol. xxxix. p. 351. This showed large movements in the line of sight as well as across the line of sight.

On June 29 a brilliant disc eruption was photographed at Srinagar, lasting for one hour between 9^h and 10^h I.S.T. This appeared suddenly near the following end of an extensive group of spots and flocculi. The bright calcium clouds extended from the central meridian to longitude 8° west, and between north latitude 7° and 20°. It is very remarkable that simultaneously smaller clouds appeared in a distant group of flocculi nearing the west limb, and in addition a large eruptive prominence was also developing on the east limb. J. E.

Solar Research in 1916.

The Solar Spectrum. — Fraunhofer's G group of the solar spectrum has been identified by Newall, Baxandall, and Butler, who have satisfactorily established that the main features of the group are produced by the well-known hydrocarbon band beginning about λ4314 (*M.N.*, lxxvi. 640). The identification is an important one, and will doubtless aid also in the classification of stars which immediately precede the Sun in type.

Sun-spot Spectra.—At the Mount Wilson Laboratory, A. S. King has investigated the origins of the band spectra which are of special interest in connection with sun-spots (*Ap. J.*, xliii. 341). The outcome of his experiments on titanium, which were made with the electric furnace, is to confirm Fowler's conclusion that the bands in question represent the actual compound titanium oxide. It was also found that the bands attributed to magnesium hydride and calcium hydride were not produced in the absence of hydrogen. The upper limit of temperature for maximum intensity

of the bands was found to be about 2300° C., which accords well with previous deductions regarding the relatively low temperature in spots.

In another paper (*Ap. J.*, xliv. 172) Dr. King gives an account of the remarkable variations in the apparent structure of the red line of lithium depending on the amount of vapour in the source. It may now be considered certain that the strong line at λ6708 in the spectra of sun-spots has its origin in lithium, and it is noted that this is the only direct proof of the presence of lithium in the Sun, since there are no lithium lines in the ordinary Fraunhofer spectrum.

From further observations in the region C–D, Father Cortie finds that there has been no substantial change in the spectra of sun-spots since the year 1882 (*Stonyhurst Obs. Rep.*, 1915, p. 12).

Radial Motion in Sun-spots.—The phenomena of radial motion in sun-spots have been further investigated by Evershed with improved instruments (*Kod. Bull.*, li.). The radial motion displacement was found to be somewhat greater on the limb side of the spot than on the side towards the centre. Usually there is an acceleration from the umbra to the outer edges of the penumbra, then a sudden fall to zero, or to a lower velocity which diminishes to zero at some distance outside the spot. The variations of indicated velocity depending upon the intensities of the lines, attributed by St. John to differences of effective level, were confirmed. Rotational movement does not appear to be a constant feature.

Solar Rotation.—During the summer of 1915 a series of spectroscopic photographs was made at Ottawa by H. H. Plaskett for the special purpose of investigating possible rapid variations in the Sun's rotation (*Ap. J.*, xliii. 145). The plates were taken in the region of λ5900, and of the lines measured, five were of solar and three of telluric origin. The deduced equatorial velocities seem to show a short-period cyclic variation with a range of 0·15 km., but the observations were not sufficiently extended to indicate any definite period. The mean of all the measures gave the equatorial velocity 0·04 km. lower than that derived in 1913. Mr. Plaskett concludes that since 1906 the rotation value has been slowly falling from 2·050 km. to 1·950 km.

The results for rotation obtained at Mount Wilson also suggest a progressive diminution of the rate since 1906. From 2·064 km. in 1906, the equatorial velocity fell to 2·053 km. in 1908, and to 1·949 km. in 1915 (*Mount Wilson Rep.*, 1915).

An investigation of the effects of haze on solar rotation measures has been made at Ottawa by R. E. de Lury (*Jour. R.A.S., Canada*, x. 345, and *Ap. J.*, xliv. 177, 198). A superposed sky spectrum, coming mainly from the central parts of the Sun's disc, would clearly tend to reduce the rotational displacements at the limb, and the measurable effects would doubtless depend in part on the characters of the lines. It is concluded that variations hitherto attributed to the Sun, including the short-period change

noted above, can be accounted for by variations in the scattered light.

In regard to the Mount Wilson observations, however, St. John and Adams have drawn attention to some further tests of the sky conditions, from which they infer that scattered radiation, whether from sky, haze, or instruments, is a negligible quantity at Mount Wilson under the usual working conditions, and is therefore not a probable source of error in the observations on solar rotation (*Jour. R.A.S. Canada*, x., 553).

Displacement of Solar Lines.—A minute investigation of the changes of wave-length of selected lines of iron in passing from the centre of the Sun's disc to the limb has been made by Evershed and Royds (*Kod. Bull.*, 49). The measures appear to show that the displacements at the centre are not due to a radial circulation on the Sun, but are probably part of a general displacement increasing from the centre to the limb. The relative shifts between the limb and centre cannot be explained by a difference of pressure in the effective regions of absorption, since the shift continues for a long distance within the limb, while a pressure effect would only be appreciable quite close to the limb. It is suggested tentatively that both limb shift and centre shift are due to a general movement of the solar gases all over the disc in a direction away from the Earth, and a method of testing this supposition by observations of Venus is indicated.

Anomalous Dispersion in the Sun.—A further reply to some of the objections which have been brought against the view that anomalous dispersion is an effective agent in solar phenomena has been given by Julius (*Ap. J.*, xliii. 43). He finds no reason to modify the principal conclusions at which he has previously arrived.

In view of Dr. Albrecht's conclusion that Rowland's measurements of close pairs of lines gave substantial evidence of mutual repulsion, such as might be explained by anomalous dispersion, further inquiry on this point has been made by Evershed (*The Observatory*, xxxix. 432). In agreement with Dr. St. John and Miss Ware (*Ap. J.*, xliv. 15), Evershed finds that Rowland's separations were almost invariably over-estimated, the errors of measurement being such as to simulate the effects of anomalous dispersion. Dr. St. John has also made a further study of the whole question, and finds that the separations of pairs are the same both in terrestrial sources and the Sun; he concludes that in so far as mutual influence of close lines is a necessary corollary of anomalous dispersion in the Sun, evidence for anomalous dispersion is entirely wanting (*Ap. J.*, xliv. 311). An experimental investigation by A. S. King (*Proc. N.A. Sci.*, ii. 461) has also given no evidence of a mutual repulsion between close lines when anomalous dispersion is active.

Valuable theoretical contributions to the discussion of anomalous dispersion phenomena have been made by Sir J. Larmor (*The Observatory*, xxxix. 103, 230; *Ap. J.*, xliv. 265).

The Spectrum of the Corona.—The discovery of a new red line, λ6374, in the coronal spectrum during the eclipse of 1914 August 21 has led to an important extension of Nicholson's theory of the coronal spectrum. It was first noted by Carrasco (*C. R.*, clxi. 631) that the new line was a member of the same cube-root series as the green line λ5303, and Nicholson (*M.N.*, lxxvi. 415) has deduced therefrom that the *coronium* atom is a simple-ring system with nucleus 7*e*. When it has eight electrons, or a single negative charge, it emits the lines 6374, 5303, 4566, 4359, 3642, 3534. The neutral and positively charged atoms yield lines which are outside the range of observation. All the remaining known lines of the corona have previously been assigned by Nicholson to protofluorine.

Photographic Study of Sun-spots.—An important contribution to our knowledge of the structure of sun-spots has been made by Father S. Chevalier, S.J., in vol. ix. of the *Annales de l'Observatoire de Zô Sè*, which includes a great number of beautiful reproductions of large-scale photographs. Among other results the photographs confirm the reality of the previously observed increase of light at the interior border of the penumbra of a spot, and throw considerable light on the structure of the penumbral filaments and their connection with the granulations of the photosphere. The bright bridges which often cross the umbra do not appear to be elevated portions of faculæ or photospheric clouds, but broad lanes of photospheric matter on the floor of the spot; the term "bridge" is therefore considered to be a misnomer. Spot outbursts appear to be preceded by faculæ, the spots first appearing among the faculæ as a few dark pores.

Solar Radiation.—In the course of an interesting paper on this subject (*Ap. J.*, xliii. 197) F. Biscoe, of the University of Warsaw, deduces from the observational data of Abbot an absolute temperature of the solar surface of 7300° ± 100° C. He also gives an account of a series of observations made in the Caucasus with an Ångström compensation pyrheliometer provided with red, green, and violet filters. He is led to express the opinion that the cause of the variations is to be sought, not in cosmical, but in terrestrial meteorological phenomena and in the methods of reduction.

This paper has since been criticised by Messrs. Abbot, Fowle, and Aldrich (*Ap. J.*, xliv. 39), who again object to the assumption of a sharply defined "black body" photosphere radiating through a thin gaseous envelope. They maintain their confidence in the evidences of solar variability which is provided by (*a*) observations of the solar constant at Mount Wilson, (*b*) comparison of Mount Wilson and Bassour observations, (*c*) comparison of Mount Wilson and Arequipa observations, (*d*) comparison of Mount Wilson and magnetic observations, (*e*) comparison of solar-constant work with solar-contrast work. Details of the solar-contrast work are given in the Smithsonian Miscellaneous Collections, vol. lxvi. No. 5, and a general summary of the year's work on solar radiation in the

Annual Report of the Astrophysical Observatory of the Smithsonian Institution.

A valuable account of the various instruments which have been employed for the measurement of solar radiation has been given by R. S. Whipple (*Trans. Optical Soc.*, 1915 March).

Solar Activity and Planetary Phenomena.—T. Köhl has found reason to believe that the northern cloud belts of Jupiter are relatively weak at times of sun-spot maximum. He also suggests that the luminosity which has occasionally been observed on the unilluminated part of Venus may occur at the same time as terrestrial auroras (*Astr. Nach.*, 4821).

An examination of the records of the planet Mars between 1862 and 1914 has led M. Antoniadi to conclude that, in general, the polar caps melt most rapidly near times of sun-spot maxima (*M.N.*, lxxvi. 413). This accords well with the view that solar radiation is greatest when spots are most numerous.

The Sun and Terrestrial Magnetism.—An interesting account of the changes in terrestrial magnetism as related to the Sun was given by Dr. Chree in a lecture to the Institution of Electrical Engineers on February 17 (*Nature*, xcvii. 509). The range of the mean diurnal variation from year to year not only varies almost exactly with the sun-spot frequency, but also shows the 27-day period. As regards disturbances, in some years there appears to be a clear connection with sun-spots, but in other years little, if any, relation is shown.

Dr. L. A. Bauer has discussed the relation between changes in solar activity and the Earth's magnetic activity, as manifested in the years 1905–1914 (*Nature*, xcvii. 493). He finds that there is a close relation between the variations in the solar constant as determined by Abbot and the changes in the Earth's magnetic constant. Also, a closer correspondence is found between these two sets of data than between either set and that of sun-spot frequencies.

From a discussion of the mean daily range of the declination for the period 1900–12, and a comparison of the curves of the mean latitudes of the sun-spots, Father Cortie adduces further evidence in support of his view that the efficiency of sun-spots in relation to terrestrial magnetic phenomena is a function of the heliographic latitudes of the spots (*M.N.*, lxxvi. 631). The efficiency of sun-spots in relation to the mean daily range in magnetic declination is greatest when the sun-spots are falling towards the equator. For magnetic disturbances the efficiency is approximately as 2 to 1 to 0·7 for latitudes 10°, 15°, 20°.

Miscellaneous.—A mathematical investigation of solar vortices has been made by Professor Störmer (*Ap. J.*, xliii. 347). It is shown that if the Zeeman effect be considered to be due to a convection current of electricity, an extremely large electric field would result. The apparent absence of the corresponding Stark effect is entirely against this, and the possibility that galvanic

currents may play an important part in sun-spots must be given serious consideration.

A theoretical discussion of the possible velocities which might result from the expansion of prominence gases has led R. J. Strutt (*M.N.*, lxxvii. 59) to conclude that the observed velocities are far too great to be attributed to the action of the same kind of forces which produce the movements in our own atmosphere. An explanation may possibly be found in repulsion by electrostatic forces.

Dr. Henroteau has drawn attention to several cases of elliptical currents in groups of sun-spots at their first appearance, as observed and drawn by him at Stonyhurst in 1915 (*M.N.*, lxxvi. 404).

A detailed account of the spectroscopic and other observations made at Theodosia by the Italian expedition during the total solar eclipse of 1914 August 21 has been published by A. Ricco (*Mem. Soc. Spett. Ital.*, series 2, vol. v.).

A preliminary report on the total solar eclipse of 1916 February 3, as observed in Venezuela, has been given by C. D. Perrine (*M.N.*, lxxvii. 65). A. F.

Double Stars.

New Pairs.—Fewer discoveries of new double stars than usual of late years have been announced. R. G. Aitken concluded his great double star survey in 1915, and the pairs found lately by R. Jonckheere are reserved for volume lxi. of the *R.A.S. Memoirs.*

T. E. Espin in *M.N.*, vol. lxxvi. p. 210, gives 74 new pairs, 45 of which are under 5″. Philip Fox, in *Annals of the Dearborn Observatory*, vol. i., publishes his first list, Fox 1 to 52; of these, 47 are new double stars under 5″.

E. D. Roe, jun., in *A.N.*, 4830, has 13 pairs, of which 5 are less than 5″. In *Popular Astronomy*, vol. xxiv. p. 613, F. C. Leonard has a note on a new double star. There are two new pairs found by F. L. Brown in *A.J.*, No. 703, one by C. P. Olivier in *A.J.*, No. 704, and three by E. E. Barnard in *M.N.*, vol. lxxvi. p. 603.

In *The Observatory*, No. 498, R. Jonckheere announces that the pair J 320, found at Lille six years ago, is not a real double star, although, with a low power, it can be measured as such. It appears with the 28-inch of the Royal Observatory, Greenwich, to be an extremely small, bright, elongated nebula, which has escaped the spectrographic surveys.

Measures.—The largest contribution of measures is this year found in the *Annals of the Dearborn Observatory*, vol. i., which contains double star observations made by Philip Fox from 1908 to 1915. This is a handsome volume of 229 quarto pages, of which the first twenty are devoted to an introduction dealing with the history of the Dearborn Observatory, and an investigation of the 18½-inch objective with which most of the observations were made. The measures are tabulated in four parts: a complete

re-measurement of the 171 Holden pairs; a similarly complete series of the 66 Küstner stars; measures of about 1200 miscellaneous stars; and a short list of pairs discovered by the author. The lists of Holden and Küstner double stars being complete are useful for reference. Each star has been measured on three or four nights, so that the volume must contain about 5000 independent observations. In Professor P. Fox, double star astronomy has found a new and energetic observer. Reviews and errata to this work are given by R. A. Aitken in *Pub. Ast. Soc. of the Pacific*, No. 165, and by E. Doolittle in *Popular Astronomy*, 1916 October.

G. Abetti in *Memorie ed osservazioni, R. osservatorio astronomico al Collegio Romano*, serie iii. vol. vi. part ii., gives his observations of double stars made from 1910 to 1913 with a 15-inch refractor. This contains measures of 387 pairs, and there is a very careful investigation of the micrometer screw, and of the accidental and systematic errors. Each star has been measured at least three times.

A second contribution from the Dearborn Observatory is a paper by another new double star observer, F. L. Brown, who, in the *Astronomical Journal*, No. 703, gives measures of 234 miscellaneous pairs obtained with the 18½-inch refractor. In most cases the stars have been measured on at least three nights.

T. E. R. Phillips has measures of 44 stars in *M.N.*, vol. lxxvi. p. 655. These are mostly of well-known Struve pairs, and some of the stars have been observed on many nights. A few of the measures were made by H. F. Acocks, the instrument used being the Coleman 8-inch equatorial of the Society.

In *A.J.*, No. 699, E. E. Barnard continues his most interesting record of measures of Sirius which he started sixteen years ago. The star seems now to be near apastron :—

Barnard	75°·1	10″·66	1915·99	40-inch
Jonckheere	74°·2	10″·57	1916·07	28-inch

From T. J. J. See's elements, R. Jonckheere derives the following positions :—

79°·8	10″·28	1916·20
75°·4	10″·65	1918·20

from which it appears that on See's orbit the observations are at present two years ahead of the calculated place.

A.J., No. 704, contains measures of 100 double stars made by Charles P. Olivier with the 26-inch refractor of the Leander McCormick Observatory. In this list, 8 pairs only are wider than 3″ separation, and many stars are of recent discovery. These inclusions from later lists are greatly needed in the present observing programmes, as most of the close pairs have not yet been re-measured. We learn that in future double star work will probably receive more attention at the Leander McCormick Observatory.

T. P. Bhaskaran in *A.J.*, No. 700, gives position angles and

distances of 65 double stars measured in the ordinary course of the Hyderabad astrographic work. As is usual in such determinations when the same pair is measured on different plates, large discrepancies are found. The magnitudes given are taken from β.G.C. or the A.G.

In *A.N.*, 4842, C. Luplau-Janssen and Chr. Hansen publish measures of 40 pairs, mostly Struve stars, observed at the Urania Observatory, Copenhagen.

E. E. Barnard gives a most extensive study of the double star Krueger 60 in *M.N.*, vol. lxxvi. p. 592. This follows the paper published eight years ago in *M.N.*, vol. lxviii. p. 629, where the parallax of the star was given as $\pi = +0''\cdot249 \pm 0''\cdot010$, a value confirmed photographically by Schlesinger and Russell. This interesting binary was first discovered by Burnham as one of the components of Krueger 60, but being a pair of magnitudes 9·6–12·0, it was evidently not thought important enough to receive a number. Since Burnham's measure in 1890 the faint star of this little pair has shown a motion of 242°. The measures of the binary and of surrounding stars will be invaluable for the independent determination of the masses. The paper is made comprehensible by the diagrams. Two interesting photographs of the triple star, taken with the 40-inch at an interval of seven years, show most plainly the motion of the system AB with respect to C, and also the quick orbital motion of AB.

R. G. Aitken in *Pub. Astr. Soc. of the Pacific*, vol. xxvii. p. 230, has a note on the re-measurement of the Aitken double stars. We learn that the author, before publishing a complete catalogue of the Aitken stars, has planned to re-measure them. Of the 420 pairs so far re-observed, 62 show angular change of more than 5°, and of these 37 give differences as great as 10°. There is a list of 16 stars with angular change greater than 40°.

Orbits and Masses of Binaries.—Only two new orbits have been published in the year. R. G. Aitken in *Pub. Astr. Soc. of the Pacific*, vol. xxviii. p. 121, gives a new investigation of β 80, and finds that orbits with periods of 95 years and of 156 years will satisfy the observed position angles with equal accuracy. Two sets of elements are given.

The second orbit is by G. Van Biesbroeck, in *A.J.*, No. 692, and is for the pair A.G.C. 11 = ζ Sagittæ. This new discussion of the observations shows that it is a quick binary with a period of only 25·20 years. The elements are followed by an ephemeris giving the positions up to 1938.

G. Van Biesbroeck has also in *A.J.*, No. 694, a study of the mass-ratios of visual binary stars. From photographic determinations Van Biesbroeck obtains the relative masses of four pairs: η Cassiopeiæ, 70 Ophiuchi, τ Cygni, and 85 Pegasi. For one only, 85 Pegasi, the fainter component is found to have the greater mass, but the case is extremely interesting, as there is a difference of five magnitudes between the components, and the brighter is only 0·36 of the whole mass. Although not accepted by Boss, this

had been found by various methods by Lewis, Furner, and Bowyer. The paper is completed by a list of 40 binaries suitable for similar determinations.

Miscellaneous Papers.—T. Lewis in *The Observatory*, No. 500, continues his instructive notes on double star astronomy. The present paper relates to eye-pieces, magnifying powers, etc., and is useful to those who wish to know how best to determine the power of the different eye-pieces they employ.

In *A.J.*, No. 700, A. Hall publishes observations of pairs of stars used for determining values of equatorial micrometer screws at the Naval Observatory, Washington.

In *Popular Astronomy*, No. 232, it is stated that the spectrum of the companion of Sirius has been investigated at the Mount Wilson Observatory, and that the line spectrum is practically identical with that of Sirius.

A.N., 4849, contains a paper by C. Luplau-Janssen on the Sun's motion and the apparent orbit of double stars.

R. T. A. Innes in *South African Journal of Science*, June, 1916, has remarks on the masses of visual binary stars. Two of his conclusions are that for solar type stars, double stars cannot exist below a separation of five times the Earth's distance from the Sun; that very faint binary stars are only found in proximity to bright stars.

The *Companion to the Observatory* for 1917 includes recent measures of well-known double stars and calculated places for 1917–1918 for pairs with separation equal to or greater than 0″·4 at the time.

Eric Doolittle has in *M.N.*, vol. lxxvi. p. 204, a paper of corrections to recent lists of new double stars.

[The Council are indebted to Mr. R. Jonckheere for this note.]

Variable Stars.

The last note on Variable Stars in the Council's Report was published in 1914. Since then the study of variables of all types has proceeded with much energy along the lines both of observation and theory.

The photo-electric cell introduced in 1913 has now established itself as an instrument of remarkable sensitiveness and accuracy in the investigation of small changes of brightness. In *Observatory*, No. 501, J. Stebbins emphasizes its great advantages as compared with the earlier selenium cell, which by reason of its irregularities presented so much difficulty in practical working.

Cepheid Variables.—Stars of this class have received a great deal of attention in recent years, and numerous important papers have been published by Wendell, Russell, Shapley, Adams, Duncan, Perrine, Guthnic, Prager, and others. Perrine, in a paper on Cepheid-Geminid variables (*Ap. J.*, xli.), has put forward the idea that the changes might be caused by an evolution of light in a secondary body as it approaches periastron, analogous

to the development shown by comets in the neighbourhood of perihelion. It seems generally agreed, however, that the available evidence on the whole weighs heavily against the supposed binary character of these stars, and perhaps Shapley's suggestion of pulsations in a single body receives as much support as any other.

It is now clear that in many stars of this class, and probably in all, spectral changes occur simultaneously with the observed variations of light and velocity. Special mention may be made in this connection of a paper on the spectrum of the typical star—*δ Cephei*—by W. S. Adams and H. Shapley (Contributions of Mount Wilson Observatory to National Academy of Sciences, No. 22), and of another by H. Shapley (*Ap. J.*, Dec. 1916), in which the variations in spectral type of 20 Cepheid variables are clearly given in diagrammatic form, as well as in figures.

Another point which has been brought to light is that the return of the maximum in Cepheid variables is not so regular as has commonly been supposed. An exhaustive investigation of the light curve of XX Cygni as a contribution to the study of Cepheid variation has been made by H. and M. R. Shapley. They based their inquiry on 300 Mount Wilson photographic determinations of the changes in light of different wave-lengths, and the analysis of 2700 visual measures by European astronomers, and conclude that the periodic recurrence of maximum so far from being clock-like in its precision, is distinctly irregular in phase and other details (Contributions of Mount Wilson Observatory, *Ap. J.*, No. 104).

Cluster Variables.—In *H.C.O. Circular*, 193, S. I. Bailey gives a preliminary account of an inquiry into the character of certain variables in the cluster *M* 5. The majority of the stars in this cluster conform to the usual type designated sub-class *a* in the discussion of the *ω Centauri* variables in *H. A.*, xxxviii. 132, but there are eight notable exceptions. The mean period of these 8 stars is only a little over $\frac{1}{4}$ day, and it is suggested that they may consist of pairs of the usual type and period, but with alternating maxima. In illustration of this hypothesis the light-curve of No. 62 is resolved into two contributory curves, each of the ordinary cluster type, but of which the combined light expressed in magnitudes is equal to the magnitude of the star at each phase. Reference is also made to the probable case of a double variable in *M* 3, and to the fact that in the cluster *ω Centauri* the variables of sub-class *c* have periods about half those of sub-class *b*. Attention is further drawn to the similarity in the mean periods of these cluster variables, the values for the stars in *ω Centauri*, *M* 3, and *M* 5 being $0^d{\cdot}549$, $0^d{\cdot}544$, and $0^d{\cdot}547$ respectively. In many cases the periods seem to be unchanged even after 10,000 returns of the maximum, but in a few instances there is a variation which can be fairly represented by a single sine term.

Eclipsing Variables.—Several papers have also been published on eclipsing binary systems. Attention may be drawn to a discussion of the elements of the systems of *TV*, *TW*, *TX Cassiopeiæ* and

T Leonis Minoris, which has been carried out by R. J. McDiarmid under the direction of H. N. Russell (*Ap. J.*, xlii.).

In *A.N.* 4833, P. Guthnic gives an account of a method of treating eclipsing binaries which show remarkable eccentricities and movements of the line of apsides.

But the most important contribution to this line of research is the considerable Memoir by H. Shapley, which forms No. 3 of the *Princeton Univ. Obs. Contributions.* In it 90 orbits are fully treated and discussed, and several general conclusions are reached. The light curves, when sufficiently well observed, are always smooth and symmetrical: the fainter component is always luminous and not dark: both components are probably darkened at the limb: the brighter star is seldom the larger: and so on. A dozen problems suggested by the research are given at the end: and it is noteworthy that the last sentences in the Memoir proper record a despair of getting direct parallaxes for eclipsing binaries. Since the Memoir was written, the Medallist of this year has revived these evanescent hopes.

Long-period Variables.—Observations of stars of this type have been continued with undiminished energy. Amongst the large mass of material now accumulating for discussion, reference may be made to the memoir of the *Variable Star Section of the B.A.A.*, communicated to the Association by C. L. Brook at the last annual meeting, but not yet published. It contains over 16,000 separate observations made by members of the section in the years 1910 to 1914 inclusive.

H. H. Turner and Miss M. A. Blagg have continued their editing and discussion of Baxendell's observations. The seventh instalment has already appeared, and the series is now nearing completion.

In *A.N.*, 4856, H. Ludendorff gives an account of *R Hydræ*, and points out the progressive shortening of the period from about 500 days near the end of the seventeenth century to a little over 400 days at the present time.

Some peculiarities in the behaviour of *o Ceti* have been discussed in papers by A. Bemporad and F. de Roy in *Soc. degli Spettroscopisti Italiani*, vols. iv. and v. Bemporad drew attention to the fact that the feeble first maximum of 1915 was the climax of progressive changes following 1910 in brightness, amplitude, and the value of $M - m$. F. de Roy has inquired into the earlier cases of faint maxima, and gets similar and accordant results, though there does not as yet appear to be any evidence of these changes being periodically recurrent.

Amongst theoretical problems relating to long-period variables which have lately come to the front is that presented by the inequalities of period so often shown by these stars. Evidence has for some time been accumulating that the attempt to represent the oscillations of the epoch of maximum by the addition of a sine term to the simple mean period is unsatisfactory, and no longer suits the facts. In some cases a combination of terms may for a

time be found to give fair agreement between theory and observation, and in a paper on the irregular variable *RS Camelopardalis* (*M.N.*, lxxvi. 7), C. Martin and H. C. Plummer infer from their discussion of that star the probability that in sufficiently extended and accurate series of observations the inequalities of long-period variables also might be satisfactorily represented by the superposition of a number of periodic terms. This view will probably be disputed, and H. H. Turner and Miss Blagg in their discussion of Baxendell's observations of *R Leonis*, *T Herculis*, and *R Persei* (*M.N.*, lxxvi. 2 and 6) have suggested *discontinuity* or sudden change of period as an alternative hypothesis to the simple sine term expedient. This seems in some cases to fit the deduced dates of maximum much better than the smoothness and regularity of a sine term, but there are many stars for which it appears equally unsuitable. In his presidential address to the B.A.A., the Rev. T. E. R. Phillips has also made reference to this question. He discussed the cases of *R Ursæ Majoris* and other stars which show considerable irregularities, and proposed as a further hypothesis continuous change of period of a non-repeating character (*B.A.A. Journal*, vol. xxvii. 1).

Another question of which the importance has been felt for some years is that of classification. In *R.A.S. Memoirs*, vol. lv., H. H. Turner had shown that the Rousdon long-period variables might be arranged in a definite sequence according to the harmonics of their light-curves. T. E. R. Phillips in the address above mentioned has followed up this matter. Making use of a much larger amount of material (the light-curves of eighty stars), and reducing the phases of the first three harmonics to the maximum of the first as reference point, and then plotting the phases of the second and third as abscissæ and ordinates, he found that with very few exceptions the stars are grouped into two distinct classes. The relationship of the harmonics is peculiar. In Class I. the phases of the first and third are almost constant, while that of the second ranges over more than 200°. In Class II. the phases of the second and third advance sympathetically, though at different rates. The following linear equations were found by calculation to represent these phases (ϕ_2 and ϕ_3) in the two classes :—

$$\text{I.} \quad . \quad . \quad \phi_3 = 202^\circ{\cdot}1 - 0{\cdot}04\phi_2$$

$$\text{II.} \quad . \quad . \quad \phi_3 = 1{\cdot}67\phi_2 - 126{\cdot}8$$

Owing to the smallness of the coefficients of these harmonics, especially the third, the individual stars naturally show somewhat large departures from the equations, but they are not larger than might be expected under the circumstances. Moreover, the distinction between the two classes appear to be supported by differences in the ranges, brightnesses, coefficients, and periods. Class I. consists of stars with smaller range, superior brightness, and shorter period on the whole, while the mean relative coefficients of the second and third harmonics are $0^m{\cdot}32$, $0^m{\cdot}15$,

and $0^m{\cdot}52$, $0^m{\cdot}21$ respectively, the coefficients of the first in each case being $2^m{\cdot}84$. The two classes of stars may be broadly distinguished by the appearance of the light curves. In Class I. the values of $m - M$ and $M - m$ are nearly equal, with a strongly marked tendency for the stars to show a pause on the rise. In Class II. the value of $M - m$ is small, the rise to maximum being short and sharp, while the decline is slow and gradual.

Irregular Variables.—In *M.N.*, lxxvi. 7, C. Martin and H. C. Plummer discuss the Dunsink photographic magnitudes of *RS Camelopardalis*. They find that it must be classed as irregular, but that the light changes can apparently be represented by the superposition of terms of about 960, 158, 96, 89, and 82 days.

SS Cygni has shown unusual activity in 1916, there having been as many as ten maxima during the year. The minima seem to have been on the average about three-fourths of a magnitude brighter than usual, and very erratic.

Reference must be made to the publication of *An Introduction to the Study of Variable Stars*, by Miss C. E. Furness, Director of the Vassar College Observatory. It contains an admirable account and summary of the historical, instrumental, and observational development of all departments of variable star astronomy, and will be found a valuable book of reference to workers in this field. T. E. R. P.

Stellar Distribution and Motions.

Many notes have been published on faint stars with large proper motions, giving data useful both for statistical purposes and for indicating the stars likely to have measurable parallaxes. It is interesting to notice the different methods that are used. The results of F. A. Bellamy and R. J. Pocock (*M.N.*, *R.A.S.*, **76**, pp. 102, 428, 538, 657) were obtained by comparing measures of astrographic plates; those of R. T. A. Innes (*Union Obs. Circ.*, No. 35) by the blink method; of M. Wolf (*Astr. Nach.*, passim) by the stereo-comparator; and the Royal Observatory, Greenwich, lists of stars with centennial proper motion greater than $20''$ (*M.N.*, *R.A.S.*, **76**, p. 585; **77**, No. 3) were found by comparison of meridian observations. The outstanding discovery of the year is a star with the largest proper motion yet known, $10''{\cdot}3$ per annum, found by E. E. Barnard (*Harv. Bull.*, No. 613) by the blink microscope. The visual magnitude is about 10, and the parallax $0''{\cdot}5$ or possibly larger, so that the absolute brightness is not more than $\frac{1}{1600}$ of the Sun. Other stars with luminosity less than $\frac{1}{1000}$ of the Sun are Groombridge 34 *comes*, and a companion to Pi 2^h 123 found by A. van Maanen (*Pub. Ast. Soc. Pac.*, **27**, p. 240). Like other feebly luminous stars Barnard's star is of type M*b*, and has a very large linear velocity in space. Another interesting star with a proper motion of $5''$ per annum, visual magnitude 10, has been found by R. T. A. Innes near α

Centauri (*Union Obs. Circ.*, No. 30); two eleventh-magnitude stars with annual motions of 2″·6 and 1″·4 have been announced by M. Wolf.

Some short lists of parallaxes have been published, but they do not include any particularly near stars. Especial interest is now centred on a new method of determining stellar distances developed by W. S. Adams (*Proc. N.A. Wash.*, 2, p. 147). It was found by Adams and Kohlschütter (*Astrophysical Jour.*, **40**, p. 385) that the relative intensity of certain spectral lines varies according to the absolute brightness of the star, and the correspondence is so close that the spectroscopic observations can be used to give a good determination of the absolute magnitude, and hence of the distance. The comparison of results found by Adams in this way with the measured parallaxes shows a remarkably close agreement; and although it is too early to judge of the exact scope and reliability of the new method, it seems likely to prove a powerful means of extending our knowledge of stellar distances and luminosities. In particular this spectroscopic criterion seems to discriminate between the giants and dwarfs of the later types with certainty.

Two determinations of the mean parallaxes of stars for different magnitudes have been published. The investigation by H. W. Unthank (*M.N.*, *R.A.S.*, **76**, p. 529) is based mainly on the Groombridge proper motions, and employs a theoretical analysis which tries to avoid giving the nearer stars an undue influence on the result—a drawback of the usual method of taking the mean parallactic motion. Sir F. W. Dyson and W. G. Thackeray's discussion (*M.N.*, *R.A.S.*, **77**, p. 7) is remarkable for the extensive data employed—upwards of 26,000 proper motions; their range of magnitude extended from $5^{m}\cdot5$ to $10^{m}\cdot3$. The chief point to determine is the factor by which the parallax diminishes for a step of one magnitude. Unthank gives the value 0·85, and Dyson and Thackeray 0·76, the latter agreeing closely with Kapteyn's result 0·78, published in 1901. Certain statistical investigations had seemed to indicate that Kapteyn's value was considerably too low, but it now appears probable that the recently found correlation between speed and absolute luminosity had caused the divergence; in any case, the confirmation by such an unprecedented wealth of material must reinspire confidence in Kapteyn's formulæ. It may often be very misleading to derive the mean distances of groups of stars by taking the reciprocals of the mean parallaxes, and there is a similar uncertainty in deriving the mean luminosities; C. V. L. Charlier (*K. Svenska Vetensk.*, **10**, No. 28) calls attention to this, and shows the importance of taking into account the range or dispersion of the absolute magnitudes of the stars considered.

It appears to be well established that the stars of type B differ very little from one another in absolute luminosity, so that the distance can be judged with fair accuracy from the apparent magnitude; this is especially the case when small differences between the different subdivisions of type B are taken into account. On this basis C. V. L. Charlier (*Lund Obs. Meddelande*, Ser. 2,

No. 14) has calculated rectangular co-ordinates for the stars of this type, 804 in number, and has discussed the shape of the galaxy which they form. The centre of the cluster lies 90 parsecs from the Sun in the direction of Carina; the cluster is of oblate form, the extension in the plane of the Milky Way being three times as great as in the perpendicular direction. The extreme diameter in the plane of the Milky Way is about 1000 parsecs, and in the direction of the galactic poles about 300 parsecs; but the stars thin out as we recede from the centre. The motions are somewhat greater in the galactic plane than at right angles to it, so that the velocity surface is an oblate-spheroid. This appears to be also the conclusion of B. Boss (*Astron. Jour.*, No. 691); and it is known that the motions of stars of type A o are similarly distributed (*M.N.*, *R.A.S.*, 75, p. 521), although in the later divisions of type A a different arrangement holds and star-streaming is strongly manifested.

The differences in the behaviour of different spectral types, the distinction of giant and dwarf stars, and the presence of a third drift, have complicated discussions of star-streaming. S. C. Meijering (dissertation published by Hoitsema, Groningen) has taken the largest homogeneous group of stars available, the K stars, and discussed Boss's proper motions of 1420 of these stars according to the two-drift theory. The results differ very little from those previously obtained from this catalogue when all the stars were taken together. In particular the division of the stars between Drifts I and II in the ratio 1·43 : 1 agrees closely with the value 1·5 : 1 for all types together. The third drift is shown very conspicuously in the diagrams which exhibit the statistics.

If any doubt remained as to the complete separation of the stars of later type into two groups of high and low luminosity (giants and dwarfs), a discussion by W. S. Adams, using the new spectroscopic method of finding absolute magnitudes, would appear to be conclusive. In *Proc. N.A. Wash.*, 2, p. 157, he has discussed 58 stars of type M; these fall into groups of high and low luminosity, with *a clear gap* of 6·4 magnitudes between them. Moreover, the same division (with a clear interval) is shown when the stars are classed according to the intensities of the hydrogen lines. This evidence supplements the results obtained by Russell from measured parallaxes in an important respect; because it might be expected that the connecting link between the two groups, if it exists, would be found among stars of moderate proper motion and brightness which do not give measurable parallaxes; these are included in Adams's discussion, but the gap remains unbridged. A discussion of the theoretical relations between the effective temperatures and densities of the stars by A. S. Eddington (*M.N.*, *R.A.S.*, 77, p. 16) gives results which seem to be in numerical agreement with Russell's theory. It is found that for gaseous stars of the same mass the effective temperature should vary as the sixth root of the density. This makes the total radiation of a giant star independent of its stage

of evolution, and accounts for the comparatively uniform brightness of the giants of all the different types.

Considerable attention has been given during the past year to the problems of globular clusters, both practical and theoretical. An important study of the colours and magnitudes of stars in globular clusters has been made by H. Shapley (*Contrib. Mt. Wilson Obs.*, Nos. 115–17; *Observatory*, 39, p. 452; *Pub. Ast. Soc. Pac.*, 28, p. 171), including a colour classification of 1300 stars in the Hercules cluster. One striking result is that the colour-index increases with brightness—that is to say, the red stars are brighter than the blue stars. The stars measured extend to about $15^{m}\cdot5$, and it is evident that the counts, except in the case of the reddest stars, have been seriously truncated by this limit. Consequently it is difficult to state precise results; but the tables apparently indicate that the average magnitude of the B stars in the cluster must be about 4 magnitudes fainter than the K stars. It is evident that only the giant stars have come under consideration; but outside the clusters the giant stars have nearly the same brightness whatever the type, the redder types being if anything the fainter. This difference in character between the cluster stars and those elsewhere seems very curious; it is confirmed by Shapley's studies of some other clusters. Assuming that the bluest stars of the cluster are comparable in magnitude with those of the same colour elsewhere (it is probable that a star cannot have the temperature giving a negative colour-index unless it has a certain minimum mass and brightness), the distance of the Hercules cluster is found to be 30,000 parsecs, and its diameter about 350 parsecs. It thus seems to be an extra-galactic object with dimensions not greatly inferior to our own system.

A. H. Joy (*Astron. Jour.*, No. 685) has determined the proper motions of 292 stars in and near the cluster M 37 Aurigæ by comparing plates taken with the Yerkes 40-inch refractor eleven years apart. The individual motions are not much greater than their probable errors. The motion deduced for the cluster as a whole is probably trustworthy; it amounts to $0''\cdot66$ per century, relative to the reference stars.

The problem of the dynamics of a globular cluster has been discussed with special reference to the law of density put forward by H. C. Plummer from the observed counts. E. Strömgren (*Astr. Nach.*, No. 4850) has discussed the orbits of stars in such a cluster. J. H. Jeans (*M.N.*, *R.A.S.*, **76**, p. 567) and A. S. Eddington (*ibid.*, p. 572) have investigated the conditions for a steady state. The former suggests that a falling off of density in the outer parts according to the law r^{-4} (instead of r^{-5}) would fit the observations at least as well, and it would be a more natural law to expect dynamically. Neither writer finds any sufficient dynamical reason for Plummer's law, if indeed it is the general law of distribution of stars in clusters. A. S. Eddington (*M.N.*, *R.A.S.*, **76**, p. 527) shows that there must be a simple relation between the extension of a cluster and the average velocities of

the stars within it; for a steady state the internal kinetic energy must in all cases be one-half the exhaustion of potential energy.

J. H. Jeans (*M.N.*, *R.A.S.*, 76, p. 552) has investigated the effects of encounters of two clusters, showing that a simple encounter would lead to a spreading out in the form of a flat disc, as in the Ursa Major cluster. More complicated encounters suggest explanations of some general features of the stellar system.

The Ursa Major "moving cluster" has been examined by L. Courvoisier (*Astr. Nach.*, No. 4832) with a view to detecting its orbital motion under the general attraction of the stellar system. If the stars are following one another round an orbit, those in front will be moving in a rather different direction from those behind. It is possible to estimate the curvature of the orbit by comparing the foremost and rearmost stars. The plane of the orbit seems to be parallel to the galaxy, and the centre of curvature is found to be distant 930 parsecs towards Cygnus. If the orbit is circular the period would be about 180 million years, which agrees very well with the order of magnitude calculated from our knowledge of the general density of stellar distribution; but the direction and distance of the centre disagree altogether with Charlier's conclusions from the type B stars, already quoted.

According to Einstein's theory of gravitation, the frequency of atomic vibrations depends on the gravitational potential at the point where they occur. It should thus be possible to determine the decrease of potential at distant points of the stellar system by observing relative displacements (towards the violet) of the spectral lines of distant stars compared with those of nearer stars, and hence to find the total mass within a given radius. There are many complications, and it seems certain that the systematic K term in the radial velocities is due mainly to other than gravitational effects; but W. de Sitter (*M.N.*, *R.A.S.*, 77, No. 2) has obtained in this way an *upper limit* to the density of matter in space, including dark stars.

In the work of Shapley on the colours of stars in clusters (*loc. cit.*), it was found that negative (*i.e.* blue) colour-indices were abundant, and the range in colour-index from $-0^{m}\cdot52$ to $+1^{m}\cdot96$ agreed with the range manifested by the stars known to be near to us. This is strong evidence against any appreciable scattering or absorption of the light in traversing the great distance (supposed to be 30,000 parsecs) separating us from the cluster; because the effect of absorption would be to redden all the stars systematically. Shapley calculates that the absorption must be less than $0^{m}\cdot01$ in a thousand parsecs. A difference in average colour-index between the inner and outer parts of the cluster may possibly point to sensible absorption in the interior of the cluster. With regard to local absorption in special regions of the sky, H. H. Turner has found evidence of obscured regions by comparing counts of bright and faint stars made on astrographic plates in a number of zones (*M.N.*, *R.A.S.*, 76, p. 149, etc.). The obscured patch can be represented approximately by the spiral $\alpha + 3\cdot66\delta = 247^{\circ}$. A. S. E.

The Motions of Spiral Nebulæ.

An accurate knowledge of the motions of spiral nebulæ, both radial and angular, would go far towards settling the status of these bodies in relation to the system of the stars. The spectroscopic linear velocities alone may indicate important dynamical relations (or absence of relation); and by comparing the radial and cross motions we could estimate the distance, and hence the size, of these bodies. The relative motions of the different parts, and particularly the rate of rotation, will also give evidence as to their nature, and perhaps determine the total mass involved. The interesting question has arisen whether the spiral nebulæ are comparatively small bodies scattered among the stars and belonging to the stellar system, or whether they are great sub-systems on the fringe of the stellar system, or, thirdly, whether they are distant galaxies coequal with our own. For the last alternative the distances must be not merely great from the ordinary standpoint, but of the order of 100,000 parsecs at least; the proper motions would have to be absolutely insensible, since a motion of 0″·1 per century at 100,000 parsecs corresponds to a linear velocity of 474 km. per sec.

Our object in this note is to survey the observational material that has been collected rather than to discuss theoretical consequences. It will be realised that the observations are of a very difficult character. The spectroscopic work involves very long exposures, during which the apparatus must be protected from changes, and the dispersion used is necessarily small. The measurements of position are made on diffuse knots which will not allow of high accuracy; and since the displacements are generally small, the unknown motions of the comparison stars may sometimes have an important influence.

The first determination of the radial velocity of a spiral nebula was made in 1913 by V. M. Slipher (*Lowell Obs. Bull.*, No. 58), who found for the Andromeda nebula a velocity of 300 km. per sec. approaching. Other investigators have found values in excellent agreement with this, as may be seen from the following:—

Wright	.	.	−304 km. per sec.
Pease	.	.	−329 „ „
Slipher	.	.	−300 „ „

M. Wolf has also made several determinations, his latest result being −450 km. per sec. (*Vierteljahrschrift*, 51, p. 115), but his results have not been very consistent among themselves.

For fainter objects the values may be more uncertain. Thus for N.G.C. 1068 the velocities +1100, +765, and +910 km. per sec. have been given by Slipher, Pease, and Moore respectively (*Pub. Ast. Soc. Pac.*, 27, p. 192); but even here there is evidently some measure of agreement.

Slipher has given radial velocities for fifteen spirals, but except

in these two cases there is no check on the results.* The average speed from his measures is between 300 and 400 km. per sec. In addition, R. E. Wilson (*Proc. N.A. Wash.*, 1, p. 183) has determined the velocity of a number of nebulæ in the Magellanic Clouds; it is true that these were all gaseous nebulæ, but presumably the results give the velocities of the clouds as a whole, and these may perhaps be regarded as objects akin to the spirals. The values for the Greater and Lesser Clouds are +275 and +158 km. per sec. The whole material is evidently too scanty as yet to derive a value of the motion of the stellar system relative to a possible super-system of galaxies, and not much stress need be laid on the provisional determinations by Truman (*Pop. Ast.*, 24, p. 111), and by Young and Harper (*J.R.A.S. Canada*, 10, p. 134)—about 600 km. per sec. towards an apex at R.A. 20^h, Dec. $-20°$. It may, however, be recalled that Sir W. Herschel's solar apex derived from only seven stars turned out to be quite near the truth, and history may repeat itself in this case.

It seems to be very doubtful whether or not spiral nebulæ show any detectable proper motions. H. D. Curtis (*Pub. Ast. Soc. Pac.*, 27, p. 216) has measured the motions of sixty-six spiral nebulæ relative to comparison stars of the twelfth to fifteenth magnitude. The average was $3''{\cdot}3$ per century, but this includes a number of large motions, to which the author attaches small weight. He considered, however, a motion of $8''$ per century for N.G.C. 253 to be worthy of confidence. The results have not yet been published in detail. A determination for a single nebula, Messier 101, by A. van Maanen (*Astrophysical Jour.*, 44 p. 210) deserves attention, since it depends on measures of a very large number of points. The motion is $1''{\cdot}2$ per century relative to thirty-two comparison stars, but since the parallactic motion of these stars would probably be of about this amount and in the appropriate direction, the result does not necessarily indicate a motion of the nebula. An attempt to determine the systematic proper motions of a large number of spirals has been made by C. Wirtz (*Astr. Nach.*, Nos. 4861, 4866), who compared recent measures with those made by Schultz at Upsala forty to fifty years earlier. He found that they were drifting towards R.A. 245°, Dec. $-3°$ (a direction almost opposite to the motion of the stars), whereas the gaseous nebulæ were moving in a similar direction to the stars. These results have been criticised by Kobold and Seeliger, the latter showing that following another method of reduction the resulting apex was nearly the same as that of the stars.

Turning now to the internal motions, spectroscopic observations have shown in some spiral nebulæ a curvature of the spectral lines, which points to a rapid velocity of rotation. Slipher detected a rotation in N.G.C. 4594 (Virgo), which is a spiral seen edgewise (*Lowell Obs. Bull.*, No. 62); Wolf found a rotation in M 81 (Ursa Major), which amounted to 100 km. per sec. not far from the nucleus; Pease found a difference between the velocities of the

* Since this was written another of Slipher's results, + 1100 km. per sec. for N.G.C. 4594, has been confirmed by Pease (*Pop. Ast.*, 25, p. 26).

nucleus and a knot in M 33 (Triangulum) amounting to 200 km. per sec.; and in N.G.C. 4594 he found a linear velocity of rotation of 300 km. per sec. at 2′ from the nucleus (*Pop. Ast.*, **25**, p. 27).

Some very interesting results with regard to internal motions have recently been obtained by the comparison of early and recent photographs. A. van Maanen (*loc. cit.*) has studied the spiral M 101. From measures of a large number of points he has found that the flow is outwards along the spiral arms. Considering the rotation, it appears that the motion of the arms is concave side foremost—opposite to that of a Catherine-wheel; thus there would be a tendency to uncurl. The motion is surprisingly large, so that at 5′ from the centre the rotation-period would be 85,000 years. For the nebula M 51 (Canes Venatici) S. Kostinsky has found indications of internal motion with the stereo-comparator (*Monthly Notices*, **77**, No. 3). His conclusions appear to agree in the main with van Maanen's. It has been pointed out by J. H. Jeans (*Observatory*, **40**, p. 60) that these results will fit in with a possible dynamical theory.

It would, we think, be premature to draw any general conclusions from these observations; but they show that a new field of astronomical investigation is rapidly being opened up, and we may hope to acquire a more definite knowledge in the near future.

A. S. E.

Einstein's Theory of Gravitation.

A Council Note in 1910 begins with the sentence, "Celestial mechanics, which has hitherto been based on the Newtonian laws of motion, is profoundly affected by the discoveries which have been made in recent years regarding measurements of space, time, and force." * These words were of the character of a prediction, for the new ideas had at that time scarcely reached the principal force with which astronomy is concerned—gravitation. But remarkable progress has been made, especially in the last two years, and there now emerges a complete and self-consistent new system of mechanics, which can be applied without ambiguity to the problems of gravitational astronomy.

Certain conclusions of modern physics have strongly suggested that there is more to be learnt about the effects of gravitation than is to be found in Newton's simple law. It is now believed that the mass of ordinary matter is due to the electromagnetic energy of the ultimate particles, and that electromagnetic energy wherever found must possess mass (*i.e.* inertia); hence the question arises whether all kinds of energy may not, in virtue of their mass, exert and be subject to gravitation. In particular the energy projected in a ray of light may be subject to gravitation and have a curved trajectory in a sufficiently intense gravitational

* *Monthly Notices*, vol. lxx. p. 363.

field—so that rays of light would be deflected by gravity. Again, it has been supposed that the velocity of light is a fundamental relation between space and time so that no effect of any kind could conceivably be propagated faster; if so, it would seem that the attraction between two bodies must be modified to some extent when their speeds become comparable with that of light.

The new mechanics, which seeks to give a precise answer to these and other questions, rests on an hypothesis of the relativity of space and time. A *restricted* principle of relativity is described in the Council Note already quoted; experimental confirmation has been ample, and no serious doubt of its truth is entertained, criticism being confined to questions of its exact scope and philosophical implications. But we are now concerned with a far wider generalisation, which must be subjected to new experimental tests. So far the consequences that can be tested observationally all lie in the domain of astronomy.

We are accustomed to locate all phenomena in a framework of space and time, to which we assign definite (*e.g.* Euclidean) properties. According to the generalised principle of relativity this framework is a mere creation of our own minds. The variables x, y, z, t which occur in our mathematical calculations have no more direct physical significance than any other of the parameters which we sometimes introduce for convenience as independent variables. *They do not indicate the location of the phenomenon in an absolute space and time.* Probably it is hopeless to try to divest our minds of all idea of location, so the theory can perhaps best be realised if we say that any four independent functions of x, y, z, t might equally well have been taken as the rectangular co-ordinates specifying the location. A little reflection will show that any physical measurement is ultimately an observation of coincidences either of material particles or more usually of light-waves. The whole progress of nature, so far as it is revealed by observation, can be resolved into an aggregate of coincidences of the values of x, y, z, and t for various entities, and it is clear that these coincidences will be unaltered if we substitute other functions of x, y, z, t to indicate the location, *i.e.* if we make any mathematical transformation of our space-time framework.

It is perhaps difficult to realise that there is no absolute framework, because with our measuring-rods and our clocks (or their substitutes) we appear to be measuring an absolute space and time of nature. But this rests on the assumption that our standards remain constant; and the fallacy of believing that our measures are absolute was revealed by the Michelson-Morley experiment, which showed that any measuring-rod, perfectly rigid in the ordinary sense, alters its length when set in motion longitudinally. The failure of the constancy of our standards leads to a reinterpretation of the meaning of our measures. We say that a length AB is one metre, but that does not mean that the distance is one metre of absolute space; it means that if the standard metre were brought and set along AB it would experience an unknown contraction or

expansion which would result in its extremities exactly coinciding with A and B. We can observe coincidences, but we cannot make absolute measures.

According to this line of argument it would appear that the truth of the principle of relativity is a matter for *a priori* discussion. But for practical applications something more is involved; for us space is filled with the luminiferous æther, and our co-ordinates x, y, z, t, which have no significance as regards location in absolute space, may be quite properly regarded as expressing definite relations to the æther. Other systems of co-ordinates would express other relations to the æther, and we should expect the form of physical laws necessarily to depend on the co-ordinates chosen. The new theory, however, makes the bold hypothesis that these relations to the æther have no effect on the phenomena and can be disregarded—a step which appears to divest the æther of the last remnants of substantiality. The hypothesis is the more acceptable because we have already become familiar with the result that uniform motion relative to the æther has no influence on phenomena; and there is a logical satisfaction in this wider generalisation. (It should be said, however, that there is matter of controversy how far the co-ordinate relations to the æther have really been eliminated by Einstein's theory; they have disappeared completely from the differential equations, but they seem to reappear in the boundary conditions at great distances.)

In finding a new law of gravitation Einstein set himself to fulfil two conditions;—(1) in accordance with the principle of relativity the equations expressing the course of nature must be the same for all transformations of the co-ordinates, since no one system of co-ordinates is more fundamental than any other, and (2) the old laws established by observation must be satisfied as approximations under ordinary conditions. We shall not attempt to give here any account of the mathematics,* and shall only state that these two conditions appear to determine the new law of gravitation uniquely. The fundamental part played by gravitation in the generalised theory of relativity is due to the impossibility of discriminating between a gravitational field and an acceleration of the framework of reference—a fact which is illustrated by our sensations of increased weight when a lift starts to move upwards.

Astronomical Consequences.—Certain results were ascertained before the theory was put in a complete form. Of these the most striking was the refraction of a ray of light by an intense field of gravitation—a result which follows, as already stated, from attributing gravitation to all forms of electromagnetic energy. The energy in a light-ray travels with the velocity of light c; if we treat it like a stream of material particles, and calculate the total angular deviation produced in passing a mass M at a distance r from

* For a general outline of the mathematical methods, see *Observatory*, vol. xxxix. p. 412, or *Nature*, vol. xcviii. p. 328. The full theory is given by W. de Sitter, *M.N.*, vol. lxxvi. p. 699, vol. lxxvii. p. 155, where references to Einstein's and other papers will be found.

its centre, the result is $2\gamma M/c^2r$. This mode of treating the problem is, however, too crude, and the actual deflection given by the complete theory is twice as great, viz.

$$\frac{4\gamma M}{c^2 r}$$

γ is the constant of gravitation, $6{\cdot}66 \times 10^{-8}$ in C.G.S. units. For a star seen close to the limb of the Sun the apparent displacement would be 1″·75. The amount seems considerable, but the difficult conditions of observations of this kind have so far prevented any observational test. For Jupiter the displacement of a star at the moment of occultation would be only 0″·017.

Another result is the displacement of all spectral lines to the red in an intense field of gravitation—that is to say, atomic vibrations are executed more slowly. This is sometimes expressed by saying that time progresses more slowly at points in the gravitational field, since the retardation affects all processes which we could use for measuring time. At the surface of the Sun the displacement is equivalent to the Doppler displacement produced by a radial velocity of 0·634 km. per sec. For a star of mass M and density ρ in terms of the Sun, the displacement is

$$0{\cdot}634 M^{\frac{2}{3}} \rho^{\frac{1}{3}} \text{ km. per sec.}$$

This velocity is in fact v^2/c, where v is the velocity in a circular orbit through the point considered. It is probable that the effect, if it exists, is masked by other uncertainties of the same order of magnitude.

Electromagnetic theory and experiments have shown that the momentum of a body moving with velocity v is proportional, not to v, but to $v(1 - v^2/c^2)^{-\frac{1}{2}}$; this leads to certain corrections in the theory of planetary motions which might be sensible, at least in the case of Mercury. If this were all, the corrections could easily have been made, but it was clear that other deviations of the same order must exist which could not be formulated so definitely. In particular it was not certain how gravitation would be affected by large planetary velocities. These difficulties have been surmounted by Einstein's theory. The complete calculation introduces in planetary theory one very important correction. An elliptic orbit will rotate in the direction of motion with an angular velocity

$$\frac{24\pi^3}{c^2} \cdot \frac{a^2}{T^2(1 - e^2)} \text{ radians per revolution of the planet,}$$

where a, T, and e are the semi-axis, period, and eccentricity of the orbit. Practically the ratio of the angular velocity of the orbit to the angular velocity of the planet is $3v^2/c^2$. For Mercury, this gives a rotation of 43″ per century—just the amount of the well-known discordance in the motion of the perihelion.

The removal of this discordance furnishes the only observational test of the new theory which has yet been applied; the effects on other planets and on the Moon are too small to be detected. To estimate the importance of this result we must consider it in

connection with the other secular variations of the orbits. There are sixteen secular variations for the four inner planets which are usually considered together. On the old theory the perihelion of Mercury was discordant by thirty times its probable error. On Einstein's theory the largest residual, that of the node of Venus, is $4\frac{1}{2}$ times its probable error—a little larger than the theory of probability predicts,* but scarcely to be considered a very serious discordance. The other residuals are all within the limits expected.

The theory has also been applied by Professor de Sitter to determine corrections to the motions of the lunar node and perigee. The corrections are not quite large enough to be checked at present; but a comparatively small increase in observational accuracy, which may be expected in the future, will render them of practical importance.

Nature of the New Law of Gravitation.—It is natural to inquire what are the chief points of difference between Einstein's and Newton's laws of gravitation. Is the force † between two masses at rest exactly according to the inverse-square? And for bodies in motion is it directed along the line of centres? Unfortunately we cannot give a plain answer. Before we can say how the force varies with the distance, we must define how the distance is to be measured. If we were to take the circular orbit of a planet, and with a measuring-rod measure first the diameter and then the circumference, we should find (if Einstein's theory is true) that the ratio is not equal to π; there would be a discrepancy of some kilometres. We have to suppose that the rod changes length systematically according as it is placed radially or transversely, so that one or other of the measures needs correction—it is impossible to say which.

For illustration we shall suppose that the transverse measures are correct and that the radius of an orbit is deduced by measuring its circumference. In making the comparison with the old law we must use the language of Euclidean geometry and Newtonian mechanics. With this convention the attraction is not exactly according to the inverse-square law even for bodies at rest; there is a small additional term—a repulsion varying as the inverse-cube. There are other forces depending on the velocity, partly radial and partly transverse. If u and v are the radial and transverse velocities, the components of force are approximately

$$R = -\frac{\gamma m}{r^2}\left(1 - \frac{2\gamma m}{c^2 r} - \frac{3u^2 - 2v^2}{c^2}\right)$$

$$\Theta = \frac{\gamma m}{r^2} \cdot \frac{2uv}{c^2}$$

* We should expect the largest of 16 residuals to be about 3 times its probable error.

† The new theory does not use the term "force" at all; we are here attempting to express the practical results of the new theory in the old terminology for the purpose of comparison.

But it must be emphasized that this is only one way of looking at the matter. It is, of course, possible to choose a system of measurement according to which the inverse-cube term would disappear. Also in accordance with Newtonian mechanics we have taken the mass to be constant, and have therefore included among the gravitational effects terms which on the electromagnetic theory would be attributed to varying mass. The relativity theory draws no such sharp distinction between the different causes which produce change of motion; we have to pass straight to the observable results without the intermediate resting-place which is supplied by the conception of force. A. S. E.

Stellar Spectroscopy in 1916.

Nebulæ.—In spectrographic observations for signs of rotation in the Ring Nebula (M 57) and the Dumb-bell Nebula (M 27), Max Wolf has found (*Sitzber. Heid. Akad.*, 1915) unsymmetrical tilt of certain spectral lines; but he has, after careful experimenting, concluded that the appearance is due to some untraced effect in the spectrograph used. On the other hand, he finds incontrovertible evidence of peculiarities in the distribution of luminosity of different vapours, as judged by the length of the spectral lines of different elements, both in the Ring Nebula and in the Dumb-bell Nebula. Similar effects have been discovered by him also in the nebula N.G.C., 2438 (*Sitzber. Heid. Akad.*, 1916).

With a spectrograph giving dispersion of 1 mm. per 20 A, Campbell and Moore have detected evidence of rotation in the two planetary nebulæ N.G.C. 7009 and 6543 (*L.O.B.*, **9**, 1). The results of two independent methods of measurement are in accord, and indicate that the rotational speed of matter in the first-named nebula at a distance of 9″ from the nucleus is of the order of 6 km./sec. In the case of N.G.C. 6543, the rotational speed is of the order of 5 km./sec. at a distance of about 3″·3. Considerations are adduced that make it not improbable that the masses of these nebulæ are several times as great as that of the Sun.

The wave-lengths of the green nebular lines have been redetermined by Campbell and Moore (*L.O.B.*, **9**, 6) from careful observations of the three nebulæ N.G.C. 6572, 7027, and the Orion nebula by comparison with titanium lines, H_β, and helium lines. The resulting values are—

Rowland System.	International System.
N_1 5007·023	5006·847
N_2 4959·080	4958·902

By corrections of the wave-lengths adopted for the comparison lines in earlier determinations, Wright (*L.O.B.*, **9**, 9) has recalculated the wave-lengths given in his observations, and finds values in good accord with those of Campbell and Moore.

The spectra of the nuclei of the nebulæ N.G.C. 6826, 418_2, and

40 have been studied by Paddock (*L.O.B.*, **9**, 29) on photographs taken by Professor Campbell for radial velocity. They disclose the characteristics of Wolf-Rayet stars, and thus tend to generalise the evidence already found by W. H. Wright (*Ap. J.*, **40**, 466). These results would appear to suggest that the Wolf-Rayet spectrum is a first step from the nebular state to a photosphere.

The spectrum of the spiral nebula M 33 has been photographed at Mount Wilson by Pease (*A.S.P.*, **28**, 33). This nebula is the faint and extended spiral in *Triangulum*. The slit of the spectrograph was set upon a bright knot, 10′ from the nucleus. The exposure was 34½ hours. The spectrum showed only three bright lines H_γ, H_β, and 5007. Adams has deduced a radial velocity of − 278 km./sec., from the photograph of which the scale was 9 mm. from H_γ to K. A second photograph, taken with a camera only 3 inches long and of aperture a little more than 1½ inches, gave a very strong spectrum of the nucleus with an exposure of 32 hours. The scale is described as 0·9 mm. from H_γ to K, and the Mount Wilson observers have been able to discern not only that the spectrum is of the type Fo, but also that a velocity of − 70 km./sec. is indicated.

The question of internal motion in the spiral nebula Messier 101 (N.G.C. 5457) has been successfully attacked by van Maanen (*Proc. N.A.W.*, **2**, 386, and more fully in *Ap. J.*, **44**, 210). It is referred to in a special Council note, page 377 *supra*.

In studying the rotation and radial velocity of the nebula N.G.C. 4594, Pease (*Proc. N.A.W.*, **2**, 517) has employed an ingenious device of multiple slits cut in a silver film on glass in suitable positions corresponding to the bright points shown in a direct photograph of the nebula. With an accumulative exposure of 80 hours he has obtained spectra from which he has deduced the velocity at five points in the nebula. The radial velocity is found to be +1180 km./sec., which compares well with the velocity +1190 km./sec. determined by Slipher.

The faint nebulosity in the neighbourhood of ρ *Ophiuchi* has been examined spectroscopically by Slipher (*Lowell Obs. Bull.*, 2, 155), who finds that the spectrum is continuous, with absorption characteristics similar to those of the star near the nebulosity. It thus appears possible that the nebulosity is visible by reason of reflected star light. A somewhat similar case has been made known to us by Slipher's earlier study of the nebulosity in the *Pleiades* (*Lowell Obs. Bull.*, 2, 26). The light of the nebula round the star Merope was found to give a distinctive spectrum similar to that of the neighbouring star.

Nova.—The spectrum of *Nova Geminorum* No. 2 was photographed with an exposure of 9 hours in 1916 February by Adams and Pease (*A.S.P.*, **28**, 80). The spectrum is still of the definite Wolf-Rayet type, with bright hydrogen lines and an exceedingly prominent bright band at λ 4686. The continuous spectrum is very strong.

Special Studies.—Photometric observations of β *Lyræ* by means of the photoelectric method are given by J. Stebbins (*L.O.B.*, **8**,

186). The observations were made at the Lick Observatory by means of a sensitive rubidium cell perfected by Professor Stebbins and Kunz in the physics laboratory in the University of Illinois. They extend over three cycles of the 12·92 day period, and while in general features they confirm the visual observations, unexplained discordances occur in successive cycles. There is a marked want of symmetry about the primary minimum.

The spectrum of γ *Argus* has been studied by G. F. Paddock (*L.O.B.*, **9**, 40) with special reference to the nature and wave-length of the Wolf-Rayet band at λ 4652. The spectrum has also been measured by Professor Fowler on photographs obtained at Johannesburg by W. M. Worssell (*M.N.*, **76**, 418).

The spectrum of v_4 *Eridani* is found to contain the enhanced lines of manganese such as Baxandall had discovered in α *Andromedæ*. These lines are noted by Paddock (*L.O.B.*, **8**, 172, and **9**, 47).

The spectrum of Barnard's star of large proper motion has been photographed by Campbell and Moore (*A.S.P.*, **28**, 207), and is found to be of type Mb similar to that of α *Herculis* (giant). W. S. Adams (*A.S.P.*, **28**, 278) finds that it has the characteristics of a dwarf star of class Mb. Seares (*A.S.P.*, **28**, 280) has determined the photographic magnitude 11·4 and colour index +2·00.

The intensity of the continuous spectrum of stars and its relation to absolute magnitude has been studied by G. S. Monck (*Ap. J.*, **44**, 45).

The origin of the absorption band in the solar spectrum near Fraunhofer's group G, with head approximately at wave-length 4314, has been traced by Newall, Baxandall, and Butler (*M.N.*, **76**, 640), who have identified it with the band usually attributed to hydrocarbon, a feature in the spectrum of the blue flame at the base of a candle-flame. The presence or absence of this band is one of the marked characteristics whereby discrimination can be made between stellar spectra of types G and F.

The interpretation of the spectral characteristics of Cepheid variables is still a matter of difficulty. One of the most remarkable features of the case is the change of spectral type first noted by Albrecht and Duncan (*L.O.B.*, **5**, 93) in the photographs of η *Aquilæ* taken by Wright. Pease's continuous observations in 1914 of *RS Boötis* showed a change of type from B8 at maximum to Fo at minimum in the period of light variation, $9^{h}\cdot1$. In a note (*Ap. J.*, **44**, 273) H. Shapley gives an account of the variations in spectral type of twenty Cepheid variables. The type is deduced (with an uncertainty stated to be one- or two-tenths of a type interval) from photographs, in which the scale of dispersion is $H_\beta - H_\epsilon = 5\cdot2$ or 12 mm., according as one or two prisms are used. (In a short note in *Proc. N.A.W.*, **2**, 208, Shapley gives a photographic reproduction under fivefold enlargement of the original spectra in the case of δ *Cephei*.) In many cases the results are illustrated by graphical representations of the light curves with the spectral type assigned at frequent epochs. It would seem as

if this remarkable piece of work carried out at Mount Wilson must throw light not only on the nature of the causes of light variation in Cepheid variables, but also on the meaning of spectral type as an indication of stages of stellar evolution.

A further paper by Adams and Shapley (*Proc. N.A.W.*, **2**, 136) deals with the change of spectral type at different epochs in the periodic variation of δ *Cephei*.

Classification.—It is announced in the 70th annual report on the Harvard College Observatory that the first step in the classification of stellar spectra for the *New Draper Catalogue* has been completed. The number of spectra classified is 233,050, covering the whole sky from north pole to south.

A catalogue of 287 stars classified according to their chemistry and temperature has been issued from the Hill Observatory, Sidmouth, as Bulletin No. V. It is a continuation of the earlier catalogue issued as Bulletin No. III., and relates mainly to stars between magnitudes 5·0 and 5·59.

The work of Adams on a quantitative method of classifying stellar spectra (*Proc. N.A.W.*, **2**, 143) and on the spectroscopic evidence for the existence of two classes of M type stars (*Proc. N.A.W.*, **2**, 157) is dealt with in the President's Address (page 395 *infra*).

Radial Velocities.—The radial velocity of β *Ursæ Majoris* has been further investigated by Professor Campbell and Miss Hobe at Mount Hamilton (*L.O.B.*, **9**, 22), with results that cannot be brought into agreement with Ludendorff's observations of 1907 (*Ast. Nach.*, **177**, 235), which indicate a period of $27^{d}\cdot16$ and a total amplitude of 15 km./sec.

The radial velocity of Barnard's star of large proper motion has been determined by Campbell, − 128 km./sec., and by Adams, − 94 km./sec. (*A.S.P.*, **28**, 207 and 278); and by Slipher, − 40 km./sec. (*Lowell Obs. Bull.*, **2**, 157).

An interesting case of two stars of common motion is recorded by Adams (*A.S.P.*, **28**, 81). The stars are A Oe 14318 and 14320, of similar magnitudes 9·6, 9·2, of similar spectrum G5 and G4, of similar proper motion 3″·76, and similar radial velocity + 300 km./sec. Russell has determined the parallax of the stars 0″·035. Hence their distance from one another is 8600 times the radius of the Earth's orbit, or about one-thirtieth of the distance to *α Centauri*. The stars are separated by 5′ in declination, and are moving in precisely the same direction at a rate of about 580 km./sec.

Variable Radial Velocities.—Observations made by the D. O. Mills Expedition disclose variable velocities in six stars, a list of which is given by J. H. Moore (*L.O.B.*, ix. 37). The stars are of classes A5, F2, B5, B4, B2, F5.

A further list of four stars is given by R. E. Wilson (*L.O.B.*, ix. 38) from the work of the same expedition at Santiago. The stars are of classes B3, B2, A, B8.

The Algol variable star *RS Sagittarii* was observed at Santiago

in 1909 for the purpose of finding variable velocity. G. F. Paddock (*L.O.B.*, ix. 39) announces that from nine photographs a range of velocity of 160 km./sec. is deduced, in good agreement with R. E. Wilson's observations in 1915.

The brighter component of the double star σ *Coronæ* has been found to be a spectroscopic binary in which the spectra of both components appear at times, both being of type F8p. W. S. Adams, who notes this fact (*A.S.P.*, 28, 80), also announces that the star Boss 5996 (A2) has variable velocity.

Observations, old and new, of the variable velocities of the stars α *Orionis* and α *Scorpii* are summarised by J. Lunt (*Ap. J.*, **44**, 250), who calls attention to the need for further observations for further revision of the orbits deduced by Bottlinger (*Ast. Nach.*, **187**, 33) and Halm (*Ann. Cape O.*, **10**, pt. 3).

Spectroscopic Binary Stars.—Orbits are given for the following stars :—

				P.	*e*.
h_4 Centauri (B5)	Paddock	*L.O.B.*,	9, 42	6^d·927	0·23
B.A.C. 5890 (F)	Parker	*Ottawa Obs.*,	2, 331	26·2742	0·49
μ Persei (G)	Cannon	,,	2, 353	284	0·06
Boss 3323 (A5p)	,,	,,	2, 369	38·3	0·07
12 Lacertæ (B2)	Young	,,	3, 65	0·1931	0·0
A Boötis (G5)	,,	,,	3, 95	211·95	0·54
α Trianguli (F5)	Harper	,,	3, 114	1·7365	0·12
14 Aurigæ (A2)	,,	,,	3, 221	3·789	0·03
B.D. 78° 412 (A5)	Lee	*Ap. J.*,	43, 320	1·271	0·0
σ Puppis (K5)	Lunt	,,	44, 261	258	0·2
σ Aquilæ (B8)	Jordan	*Alleg. Obs.*,	3, 189	1·9502	0·0
T Vulpeculæ (F)	Beal	,,	3, 197	4·4358	0·44

Work in the Laboratory.—In new observations of the spectrum of silicon, Fowler (*M.N.*, **76**, 196) has found four lines which from their behaviour under suitable conditions must be classed in Lockyer's group IV., developed when condensed discharges are utilised. Lines of this group were found by Lockyer to be characteristic of the earliest varieties of the B stars. Fowler now finds that his four lines occur in the spectrum of β *Crucis*, a star of type B1.

In a further note on the nature of the coronium atom (*M.N.*, **76**, 415), Nicholson has been led (by the discovery by Deslandres and by Carrasco of a new strong line in the red part of the spectrum of the solar corona observed in 1914 August) to a remarkable completion of his analysis of the spectrum of the corona. His earlier researches enabled him to assign all the observed lines except five to a hypothetical element protofluorine, with a positive core or nucleus with charge 5*e*. He now assigns

the remaining five lines, including the well-known line at 5303, to an element which he consents to allow the name coronium, with a positive nucleus with charge $7e$ and a simple ring system. When the ring contains eight electrons—thus having a single negative change—it emits the five lines unaccounted for in his earlier work.

The banded spectra ascribed to titanium oxide, magnesium hydride, and calcium hydride have been studied in the electric furnace by King (*Ap. J.*, **43**, 341), who finds clear evidence that the bands connected with titanium appear in the presence of oxygen, and that those connected with magnesium and calcium appear in the presence of hydrogen, and that the temperature of about 2300° C. seems to be the upper limit for the greatest strength of the bands.

The spectrum of iron in the oxyhydrogen flame has been studied by Sir Norman Lockyer and H. E. Goodson (*Proc. R.S.*, **92**, 260).

The structure of broadened spectrum lines has been investigated by Merton (*Proc. R.S.*, **92**, 322) by means of a Fabry and Perot interferometer.

A note on the pole effect in the spectrum of calcium has been published by Gale and Whitney (*Ap. J.*, **43**, 161). It has special reference to the effect in triplets of the first and second subordinate series. In a second paper (*Ap. J.*, **44**, 65) Whitney gives the pole effect for all the principal lines of calcium spectrum.

The decomposition of spectral lines in an electric field was discovered by Stark and by Lo Surdo in 1913. The effect has been studied by Janet Howell at Mount Wilson (*Ap. J.*, **44**, 87).

Instruments.—The 72-inch reflector which is being erected on the summit of Saanich Hill, Victoria, B.C., is described by Plaskett (*Jour. R.A.S. of Can.*, 1916, p. 276) with striking illustrations of the pier, dome, and instrument. A description of the tests made to ascertain where the conditions were most suitable for this instrument is given by W. E. Harper (*Ott. Publ.*, **2**, 275).

A site has been chosen for the 1½-metre reflecting telescope of the National Observatory of the Argentine Republic. It is described by C. D. Perrine (*A.S.P.*, **28**, 253) as being situated near the southern extremity of the Sierra Chica, about 40 kilometres south-west of Cordoba, at a height of 4000 feet above sea-level.

H. F. N.

"Summer" Time.

Though astronomy and navigation are specifically excluded from the operation of the Act, of which the above is the short title, an alteration of public time is sufficiently akin to our subject to demand notice here.

About the year 1907 Mr. William Willett, the head of a firm of London builders and estate agents of reputation, and a Fellow of our Society, conceived the notion that it would be for the good of

the community if business, and life generally, began earlier in the solar day than they do in the summer months of the year, in order to have more daylight in waking hours. He proposed to effect this by an alteration of the clocks of the country, which should be set forward by some desired amount so that mean noon should be earlier than twelve by the clock; and he advocated this scheme by circular and by notices in the press, under the heading "The Waste of Daylight." In 1908 Mr. Robert Pearce, member of the House of Commons for Leek, Staffordshire, and also a Fellow of our Society, presented a Bill to promote the earlier use of daylight in certain months of the year. In this Bill, known as the Daylight Saving Bill, it was proposed that twenty minutes should be dropped from the hour between two and three o'clock in the morning of each of the first four Sundays in April, so that during the summer months the clock would be eighty minutes in advance of Greenwich Mean Time, and that twenty minutes should be added to each of these four defined hours in September. The time thus established was to be known as British Time. The Bill passed its second reading in the House of Commons on 1908 March 26—a report in *The Times* says "amid laughter and ironical cheers," and a note in the same paper says that the passing was due to some parliamentary accident; but the Bill was referred to a Select Committee, and the subject was then fully discussed. Sir William Christie, Sir David Gill, Sir Robert Ball, Dr. Rambaut, and Dr. W. N. Shaw among others stated their views. The first two and Dr. Shaw were opposed to the Bill, Sir Robert Ball and Dr. Rambaut spoke in its favour. The Committee amended the Bill by proposing that the change should be made by putting the clock forward one hour on the third Sunday in April, and one hour backward on the third Sunday in September of each year, and reported to the House in this sense. The Bill thus amended was reintroduced by Mr. T. W. Dobson, member for Plymouth, on 1909 March 5, and the second reading was carried by 130 to 94. The Bill was again referred to a Committee, who examined twenty-four witnesses, and the Chairman drafted a Report in its favour, but the Report was rejected by a majority of one, and the Committee recommended that the Bill be not further proceeded with owing to great diversity of opinion and to "doubts which have been expressed as to whether the objects of the measure can be attained by legislation without giving rise, in cases involving important interests, to serious inconvenience." It was suggested that the Bill would be again brought forward by Mr. Pearce in 1911, but this was not done, and there is good reason for saying that the Government did not intend that the measure should become law. However, last year, owing to the necessity for economy in lighting, the Government adopted the scheme, and a resolution approving the principle of altering the clock passed the House of Commons on 1916 May 8 by a majority of 170 to 2. On the next day Mr. Herbert Samuel, President of the Local Government Board, introduced a Bill, which quickly passed through all stages, and was made law on 1916 May 17. Clause 1

of the Act, which is known as the Summer Time Act (1916), runs as follows :—

(1) During the prescribed period in each year in which this Act is in force, the time for general purposes in Great Britain shall be one hour in advance of Greenwich Mean Time.

The next clause explains that this was to be in force in the year 1916, and that the prescribed period during that year was from May 21 until October 1 two o'clock in the morning of each day, but that in any other year during this present war the Act may be brought into force by an Order in Council for any specified period. The Act also applied to Ireland, Dublin Time being substituted for Greenwich Time.

Proclamation was made in the press and by placard, and on the night of Saturday, May 20, clocks of all kinds were put forward one hour, and the community lived by this altered time, apparently without inconvenience, though there were a few expressions of dissatisfaction with the scheme. In September proclamation was again made in the same way, and on the night of Sunday, September 30, the clocks were put back one hour, and so Great Britain reverted to Greenwich Time.

The scheme was adopted, and we believe also carried into effect, in Austria, Denmark, France, Germany, Holland, Italy, Norway, Sweden, and Portugal.*

It may be noted that the Ordinances above mentioned are the first which specify Greenwich Time or any other time, as the time to be used for general purposes. The Statutes (Definition of Time) Act, 1880, which is the first British enactment dealing with time, removes doubts as to expressions of time in Acts, deeds, and legal instruments, but does not ordain any system for general use.

H. P. H.

Zone Standard Time.

Following the above legislation, the Time (Ireland) Act became law after very little opposition on 1916 August 23, and thus after many years' agitation of the question the time adopted for use in Ireland was assimilated to that adopted for use in Great Britain. The Act came into force on 1916 October 1, and is to operate when the Summer Time Act is in force as well as at other times.

Opportunity may be taken to say here that since the last note on the subject in these pages there have been several additions to

* Since this note has been written a Parliamentary Committee appointed to inquire into the working of the scheme in Great Britain has reported that they found a strong feeling in favour of the reform throughout the kingdom, and it is announced that the Act will be brought into force in these islands this year (1917) from April 8 until Sept. 23. It is learned from announcements in the daily press that the clocks will be advanced in France and Algeria on March 4, and in Germany on April 1.

the list of nations and Governments that have adopted the Zone Standard Time system. The most important perhaps of these is Brazil, which is divided into three zones, the time of these being respectively three, four, or five hours slow on Greenwich. In certain Brazilian islands in the Atlantic the time is two hours slow. In some West Indian islands the time four or five hours slow has been adopted. The time in Fiji is now twelve hours fast, that of Samoa $11\frac{1}{2}$ hours slow, in the Sandwich Islands $10\frac{1}{2}$ hours slow, and there are other additions which are given in detail in other places.

H. P. H.

List of Public Institutions and of Persons who have contributed to the Library, etc., since the last Anniversary.

His Majesty's Government in India.
The Lords Commissioners of the Admiralty.
British Association for the Advancement of Science.
British Astronomical Association.
British Horological Institute.
Institution of Electrical Engineers.
London, University College.
Meteorological Office.
National Physical Laboratory.
Optical Society.
Physical Society of London.
Royal Institution of Great Britain.
Royal Observatory, Greenwich.
Royal Photographic Society of Great Britain.
Royal Society of London.
Cambridge Philosophical Society.
Cambridge University, Solar Physics Observatory.
Chatham, Royal Engineers' Institute.
Dublin, Royal Irish Academy.
Dublin, Royal Society.
Edinburgh, Royal Observatory.
Edinburgh, Royal Society.
Leeds Astronomical Society.
Manchester Astronomical Society.
Manchester Literary and Philosophical Society.
Oxford, Radcliffe Observatory.
Oxford, University Observatory.
Salcombe Regis, Hill Observatory.
Stonyhurst College Observatory.
Adelaide Observatory.
Albany, N.Y., Dudley Observatory.
Allegheny Observatory.
Amsterdam, Koninklijke Akademie van Wetenschappen.
Antwerp, Société d'Astronomie.
Arcetri, Reale Osservatorio.
Barcelona, Sociedad Astronomica.
Basel, Naturforschende Gesellschaft.
Batavia, Royal Magnetical and Meteorological Observatory.
Bombay and Alibag, Government Observatories.
Bordeaux, Observatoire.

Calcutta, Astronomical Society of India.
Canada, Royal Society.
Cape of Good Hope, Royal Observatory.
Cape Town, Royal Society of South Africa.
Cape Town, South African Association for the Advancement of Science.
Catania, Reale Osservatorio.
Catania, Società degli Spettroscopisti Italiani.
Chicago, Society for Practical Astronomy.
Cincinnati Observatory.
Copenhagen, Kongelige Danske Videnskabernes Selskab.
Copenhagen, Observatorium.
Cordoba, Observatorio Nacional Argentino.
Egypt, Survey Department.
Europe, Association Géodésique Internationale.
Evanston, Illinois, Dearborn Observatory.
Geneva, Société de Physique et d'Histoire Naturelle.
Genoa, Istituto Idrografico.
Granada, Observatorio Astronómico, Geodinamico y Meteorológico.
Halifax, Nova Scotian Institute of Science.
Harvard College Astronomical Observatory.
Helsingfors, Finska Vetenskaps Societet.
Helwân Observatory.
Hobart, Royal Society of Tasmania.
Hyderabad, Nizamiah Observatory.
India, Survey Department.
India, United Service Institution.
Japan, Astronomical Society.
Johannesburg, Union Observatory.
Kodaikánal and Madras Observatories.
Lick Observatory.
Lisbon, Observatorio Astronomico.
Lowell Observatory.
Lund, Astronomiska Observatorium.
Madrid, Observatorio Astronomico.
Madrid, Real Academia de Ciencias.
Mauritius, Royal Alfred Observatory.
Melbourne Observatory.
Milan, Reale Osservatorio di Brera.
Missouri University, Laws Observatory.
Montpellier, Académie des Sciences et Lettres.
Mount Wilson, Solar Observatory.
Neuchatel, Observatoire Cantonal.
New York, Observatory of Columbia University.
New Zealand Department of Lands and Survey.
Northfield, Minn., Goodsell Observatory of Carleton College.
Oporto, Academia Polytechnica.
Ottawa, Dominion Astronomical Observatory.
Paris, Académie des Sciences.

Paris, Bureau des Longitudes.
Paris, Observatoire.
Paris, Observatoire de la Société Astronomique de France.
Paris, Société Astronomique de France.
Paris, Société Mathématique de France.
Paris, Société Philomathique.
Paris, Université.
Perth Observatory, Western Australia.
Perth, Western Australian Astronomical Society.
Philadelphia, American Philosophical Society.
Philadelphia, Franklin Institute.
Philadelphia, University of Pennsylvania.
Pomona College Astronomical Society.
Pulkovo, Observatoire Central Nicolas.
Rio de Janeiro, Observatorio.
Rome, Reale Accademia dei Lincei.
Rome, Società Italiana delle Scienze.
San Francisco, Astronomical Society of the Pacific.
Stockholm, Kongliga Svenska Vetenskaps-Akademie.
Stockholm, Observatorium.
Sydney, Royal Society of New South Wales.
Tacubaya, Observatorio Astronómico Nacional.
Toronto, Royal Astronomical Society of Canada.
Toronto, Royal Canadian Institute.
Tortosa, Observatorio del Ebro.
Toulouse, Observatoire Astronomique.
Travancore Observatory.
Turin, Reale Accademia delle Scienze.
Turin, Reale Osservatorio di Pino Torinese.
Turin, Società Urania.
Utrecht, Observatoire Astronomique.
Washington, Carnegie Institution.
Washington, National Academy of Sciences.
Washington, Navy Department.
Washington, Smithsonian Institution.
Washington, United States Coast and Geodetic Survey.
Washington, United States Naval Observatory.
Zürich, Naturforschende Gesellschaft.
Zürich, Schweizerisch Geodätische Kommission.
Editors of the "American Journal of Mathematics."
Editors of the "American Journal of Science."
Editor of the "Astronomical Journal."
Editor of the "Astronomische Nachrichten."
Editor of the "Astronomischer Jahresbericht."
Editors of the "Astrophysical Journal."
Editor of the "Athenæum."
Editor of Brown's Nautical Almanac.
Editors of the "Bulletin des Sciences Mathématiques."
Editor of the "English Mechanic."
Editor of "Knowledge."

Editor of "Nature."
Editors of "The Observatory."
Editors of "Popular Astronomy."
Editor of the "Revue du Ciel."
Editors of "Terrestrial Magnetism."

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Prof. Max Wolf.

ADDRESS

Delivered by the President, Professor R. A. Sampson, on presenting the Gold Medal of the Society to Mr. Walter Sydney Adams.

The Council has decided to award the Gold Medal to our Fellow and Associate, Mr. Walter Sydney Adams, of Mount Wilson Observatory, California, for his investigations in Stellar Spectroscopy, including the determination of Absolute Magnitude. It is my duty to lay before the Society to-night the grounds for this award.

The outline of Mr. Adams's scientific activity is a simple one. In 1898 he was attached to the staff of Yerkes Observatory as a Fellow in Astronomy. He remained there till 1904, when Mr. Ellerman, Mr. Ritchey, and he accompanied Professor Hale to form a nucleus of the staff at Mount Wilson. Latterly he has been Assistant Director of the Observatory. During these seventeen or eighteen years of his work he has produced a series of notes and memoirs engaged with solar and stellar spectroscopy, of which the number appears to be about fifty, and many of which embody prolonged labour, both in observing and in collating.

It is to my judgment a sign of a rightly managed observatory when it is not possible always to separate clearly the contributions of the various members of the staff. This proposition, like the H and K lines of the Solar Spectrum, can be made to appear also under the form of a double reversal, or rather, as one of several: as, that an observatory is wrongly managed where each man's credit is distinct; or that it is rightly managed where it is possible to confuse the parts contributed; and so on. I would guard myself formally against seeming to affirm any one of these, though I suppose I cannot logically escape from affirming some one among them all. Be that as it may. It is a fact that some minds work best alone, and some more naturally in association. We find a substantial proportion of Mr. Adams's papers written in collaboration now with one colleague, now with another; Adams with Frost, Adams with Hale, with Gale, with Kapteyn, with Kohlschütter, with Shapley, with Pease, with Miss Lasby and with Miss Burwell. We can admit, as ought to be, that there was mutual assistance in all these cases, which the authors themselves did not desire to divide. In a long series of this kind an experienced reader will not find difficulty in recognising the merit he is in search of, and I imagine it is specifically the duty of your Council, using their knowledge of the circumstances of observatory work, to admit such collaboration in making their award, and not to seem to put a premium upon half-effective isolated work or selfish credit-hunting.

There are times and positions, there are directions, in the history of science, where no real advance can be made except by an act of genius. Naturally there is no time when genius does not find its field and opportunity. But there are times too when the greatest, the indispensable need is well-directed spade-work.

Mr. Adams has set himself with undivided purpose, along with his colleagues, in connection with a great institution, to do the spade-work of spectroscopy; the work is well and truly done, and at the end I shall have to tell you how the spade has turned up a veritable pot of gold. I recall a passage of Roscoe's, in which he anticipates the advent of a Newton some day to interpret the spectrum to us. No Newton has arrived so far; to wait for one would be ignoble; bit by bit we seem to be winning through without him. And as we go on we realise that early investigators little knew the delicacy and riches of their own material and its almost infinite possibilities for interpretation of the structure of the atom or molecule that yields the spectrum, of the circumstances under which it originated, and of its history on its passage to us.

The distinct spectra produced by arc and spark, peculiarities of enhanced lines, the Doppler effect, pressure shift, the Zeeman effect, wings, broadening, density, diffuseness, bright, reversed and doubly reversed lines, rhythmic series, bands, give indications obviously full of meaning, and as yet imperfectly explored, of states of temperature, pressure, atmosphere, combination of elements, motion, magnetic field, and other circumstances of the genesis of the spectra. In the same spectrum different lines and different collections of lines behave in distinct ways under the same stimulus. I may take in illustration two papers by Gale and Adams in collaboration * on the pressure shift of lines in the spectra of iron and titanium. The subject was not new; but in the spectrum first-hand knowledge of the phenomena is essential, and it was necessary to repeat the experiments with special view to the ranges of pressure that might be expected in the reversing layer of the Sun and stars of like class. Both spectra contain very many lines, and they behave with extraordinary variety under pressure; some are reversed symmetrically, some unsymmetrically; some remain bright and fairly narrow under pressure, some are bright and symmetrically broadened, some broadened very unsymmetrically towards the red; yet another class, as if to defy any facile theory, shows a displacement towards the violet. Again, there is the distinction of behaviour of arc, flame, and enhanced lines. These are the circumstances; it is not within my purpose to summarise the conclusions, which, generally speaking, are a confirmation of the work of Duffield, Humphreys, Hale, and St. John. But I would remark that it seems as if before the end we should have to schedule the behaviour of each individual line,

* *Astrophysical Journal*, 35 (1912), p. 10; 37 (1913), p. 391.

just as we catalogue the proper motion of every star. Certainly the researches of which I have to speak further to-night, and which form the field of Adams's labour, chiefly depend for their success upon the detection of the idiosyncrasies of particular lines in the solar and stellar spectra, and it would be obtuse to suppose that they are anything but the opening of a door. I propose to give you a summary of his researches, as far as time permits and as far as they are suited to summary, but it is less my intention to give an adequate list of the contents of all his papers than to convey a picture of sedulous examination of every feature of his subject, never, it would seem, with a sensational intention or declared hope, but by a practical process of exhaustion to make sure not to miss anything that was within the scope of his resources.

I think it will be clearest if I arrange these writings, not chronologically, but in groups according to their subject. Without difficulty we may group them under the heads, (i) instrumental and laboratory studies; (ii) papers on sun-spots and other features of the solar surface, including papers on the solar rotation; (iii) radial motion and spectroscopic binaries; (iv) spectra of particular stars; and (v) general considerations relating to spectra, leading up to the momentous discovery—of which he is careful to share the credit with another—of the possibility of predicting parallax.

A description of the spectrograph employed at Mount Wilson should not be passed over,* for instrumental points are quite as important as general ideas. I would ask your indulgence, however, here and in what follows. I cannot but feel that I may miss some critical feature, and for your sake I wish the duty had fallen to one who was a regular student of the spectroscope. It was with the 60-inch telescope that most of the work was done. This telescope of Professor Ritchey's, massive as it is, is certainly the most flexible instrument that was ever constructed. It is capable of use as a Newtonian, and in three different ways as a Cassegrain. Similarly it has three spectroscopes. One, for the spectra of faint stars, is of low dispersion, and is fitted at the Newtonian focus with a short camera. One is a very powerful instrument, used only for the brightest stars; it is attached in fixed position when the telescope is used as a Cassegrain with equivalent focal length of 150 feet, the beam passing by reflection down the polar axis; the spectroscope is of the auto-collimating type, with 18 feet camera, and gives a scale which runs from 6·2 A. to the millimetre at Hα up to 1·4 A. at Hγ. The third instrument, the one most frequently used, is fitted with one, two, or three prisms and cameras from 40 inches to 7 inches in length, varying the scale according to the star from 5 A. to the millimetre down to 96 A. Several thousand spectra have been taken with one or other of these combinations, all with slit and comparison spectra, and are available for classification, radial motions, and

* *Astrophysical Journal*, 35 (1912), p. 163.

other detailed work. The following particulars of exposure times are of technical interest.* The definition is on a scale of 5.

Star.	Mag.	Spectrum.	Exposure Time.	Slit-Width.	Definition.
			min.	mm.	
Lal. 27742	6·8	G2	27	0·038	3
W.B. 15^h720	6·8	G9	30	·038	3
Groom. 1855	7·4	G8	61	·038	3–4
OΣ 298	7·9	Ko	75	·038	3–4
Lal. 5761	8·0	A3*p*	77	·038	3
Groom. 34	8·2	Ma	122	·038	2–3
Lal. 21185	7·6	Ma	92	·038	4

Let me next pass in rapid review the papers on the solar surface. They are a good example of the joint work of the staff at Mount Wilson, and of the way long-standing problems of the Sun's surface are dealt with there, defined, isolated, and followed to their inmost lairs, and, we must say to a large extent, solved. One does not fail to see Hale's hand. Under his direction research always seems to find its point. Instrumental and laboratory resources, great to begin with, grow to meet the requirements of the problems as they arise. Questions are divided or handed on from one member of the staff to another. One knows that it is one of Professor Hale's anxieties to encourage the amateur, and keep the small man alive. I should agree that in that view he shows as much wisdom and foresight as in his great organisation. The everlasting paradox of things is not going to fail, at this period of the world, to humble the mighty and exalt them of low estate—from time to time. Still, we shall not pass this organisation under our view without offering afresh our admiration, not dazzled or discouraged or envious, for a growth that I believe has had no parallel in astronomy since Tycho built Uraniborg.

Three of the papers I have to refer to are in collaboration with Professor Hale, one of them with Mr. Gale as well.† They establish the fact that the differences shown between sun-spots and the disc are in fact just temperature differences, the sun-spot being at a lower temperature. It is not a recondite result. It had been implied before by Lockyer, perhaps not very clearly. It might be said and unsaid half a dozen times in speculation without attracting attention or possessing importance. It is therefore worth while to point out how the papers in question handle it.

Taking the metals titanium, chromium, vanadium, iron, and manganese as touchstones, their spectra were produced for comparison with the spark, a high current arc, a low current arc, a synchronous alternating arc devised by Professor Crew, and the electric furnace, and differences were shown which with little doubt must be

* *Ap. J.*, **39** (1914), p. 342.
† *Ap. J.*, **23** (1906), p. 11 ; **24** (1906), p. 185 ; **25** (1907), p. 75.

ascribed to temperature merely. The relation of these results to the spot spectrum may be illustrated by the table :—

Element.	No. of Lines Strengthened in Spots.	No. of Lines Strengthened in Weak Arc.	Unchanged in Weak Arc.
Ti	88	83	5
Cr	46	42	4
Fe	19	18	1
V	56	52	4
Mn	11	9	2
	220	204	16

It is clear that the lines strengthened in spots are those strengthened in the weak arc, pointing to the conclusion that the spot temperature is below that of the general solar surface.

The conclusion is certified by the identification of a vast number of lines with the fluted spectrum of titanium oxide. I cannot here pursue the matter as it deserves, nor do more than mention the confirmation afforded by Fowler's subsequent detection of the lines of magnesium hydride in spot spectra, and of calcium hydride by Olmsted, nor need I say that the matter is not ended with one conclusive stroke. It is the subject of a further elaborate review under Adams's name in 1909,* and Mr. Evershed has also dealt with it in several of the Kodaikánal Bulletins.

While still at Kenwood, Hale had photographed certain bright chromospheric lines without an eclipse by setting his slit strictly tangential to the Sun's limb. He carried on this work at Yerkes, and one of his joint papers with our medallist is upon the same subject. Adams, with Miss Burwell, took it up again in much greater fulness, showing among other things that he was able by this method to equal the best eclipse results — for example, Mitchell's—and also to reach a lower level of the chromosphere, that the heavier metals show up more strongly as the level falls, and that an absorption spectrum that presents itself at the same time differs from the normal spectrum by the same characteristics as Hale and Adams found in comparing the disc with the limb. These results remove an important group of questions from their sole dependence upon the precarious region of eclipse observations.

Returning to the question of the disc and the limb, let me describe at somewhat greater length a paper published under Adams's sole name in 1910† upon that subject. The matter originated in a remark of Halm's made while determining the Sun's rotation with the heliometer at Edinburgh, namely, that the comparison of the limb and centre showed that generally the lines at the former were displaced to the red, as would be the case under pressure, to which in fact he ascribed it, supposing that the lower levels of greater pressure contributed a greater proportion of the

* *Ap. J.*, 30 (1909), p. 86. † *Ap. J.*, 31 (1910), p. 30.

appearance at the limb than they do at the centre. An earlier investigation of Mr. Hale and our medallist upon the subject* showed three clear features in the limb spectrum, which up to then had been supposed singularly little modified except by general absorption, viz. a weakening and disappearance of the wings shown by many of the strongest lines at the centre of the Sun; second, a slight widening in the case of nearly all lines; and third, a strengthening or weakening of certain lines which in general closely corresponds to the strengthening or weakening of the same lines shown in sun-spots. At the same time it was clear that a more searching investigation was wanted, and this Mr. Adams undertook with the 30-foot spectrograph of the tower telescope, upon very much the same plan as is used for the rotation of the Sun, except that he observed only upon the Sun's equator, and compared the east and west limbs with the centre of the disc instead of directly with one another. The half sum of the displacements shown would then give the solar equatorial rotation, while the half difference gave the displacement of the line which was characteristic of its origin at the limb. No plate was included which did not give a reasonably accordant value of the rotation, for it is a baffling feature of this work that isolated plates to which by inspection no exception can be taken, may give outstanding results for this constant. Adams's value for the resolved component in the line of sight for 1908 was 1·86 km./sec.; the mean of the present series is 1·87 km./sec.; the range included among plates retained is from 1·70 km./sec. to 1·98 km./sec., a range which is comparatively small beside the other shifts under consideration. Forty-two plates were obtained, covering the spectrum from λ3818 to λ6420, or from below K up to C. As may be supposed, some difficulty was experienced in keeping a research begun upon so comprehensive a plan within reasonable limits. Eventually it was confined to the following programme:—

(1) all prominent enhanced lines;
(2) all lines of calcium, magnesium, sodium;
(3) the measurable lines in the cyanogen flutings;
(4) the α and γ lines of hydrogen;
(5) lines of elements like lanthanum and cerium of very high atomic weight;
(6) a large number of lines of iron, titanium, vanadium, chromium, and other elements distributed as uniformly as possible throughout the spectrum;
(7) lines specially strengthened or weakened in the spectrum of the Sun's limb, making 470 lines in all.

On making the measures a problem arose which is characteristic. It is accepted that the fluted spectrum of cyanogen is not displaced by any agency except motion in the line of sight. Now a small but distinct displacement appeared which could not be ascribed

* *Ap. J.*, 25 (1907), p. 300.

to line-of-sight motions at the limb, for these were verified by the values found for the rotation, and must then be ascribed to line-of-sight motions at the centre. Assuming that there is upon the average a displacement due to rising gases which at the centre of the disc are approaching us, its value was determined on the supposition that the cyanogen bands were undisturbed, and the resulting allowance subtracted from the whole of the other readings. The modification is not very great, but it forces Mr. Adams to bring under review a double set of results, the modified and the unmodified ones, neither of which can be dismissed, though neither is entirely satisfactory. I do not propose to take you over the conclusions of this discussion, which would require to be very carefully stated with all their qualifications, and some of which are still in debate; I shall only point to one arresting exception that declares itself. It is that while we conclude that the cause of the changes are seated in the lower strata from the absence of displacement effect in hydrogen, calcium, and other high-level lines, yet we find that the deep-seated heavy elements lanthanum and cerium show very little displacement too. Such a fact proves the necessity for so careful a survey, and produces, in me at least, a confirmed scepticism of ready generalisations that are not based upon such scrutinies.

Mr. Adams's general conclusion is that Halm's surmise is correct, and that the features shown upon the whole are evidence of a higher pressure in the strata which the lines of the limb stand to represent, and that they cannot be explained as line-of-sight motions. As to some of these conclusions I would mention that Mr. Evershed, certainly with good ground, takes a critical position.* Nor do I wish to magnify Adams's work here or elsewhere into an oracle. That would misrepresent equally it and him. The problems require unravelling. When one or another is unravelled there may be so much of it that it is almost as puzzling as before. My aim is merely that you should understand the nature of the task and the manner in which Adams has gone to work.

The rate of rotation and the law of change with latitude of the solar photosphere may be called the first step in the spectroscopy of displacement of spectral lines. The comparisons for the Doppler effect are here all to hand, either by matching the approaching and receding limbs of the Sun directly with one another, or by the mediation of unshifted atmospheric lines. Dunér at Upsala first measured the effect in 1890, working visually. Halm at Edinburgh, working with Gill's heliometer, also visually, distinctly improved the accuracy, and in the course of it found the significant alteration of the whole of the limb which led to comprehensive researches later on the same matter by our medallist and others. Sir Frank Dyson, while at Edinburgh, again improved upon Halm's methods, introducing photography and a large-scale image of the Sun, and at Cambridge and at Ottawa also the same

* *Kodaikánal Bulletin*, No. 39 (1914).

problem has been handled by modern methods. It was among the original proposals to engage the Mount Wilson Observatory. In 1906–7 Mr. Adams made a determination with the Snow telescope, a horizontal beam and an 18-foot camera.* In 1908 he made a second with the tower telescope and 30-foot camera.† In 1909 the same apparatus was employed to compare the two limbs separately with the centre of the disc, and led to a third determination, at any rate, of the rotation at the equator—this I have already described; while a fourth study, made also with the tower telescope and 30-foot spectrograph, was occupied specially with the behaviour of hydrogen lines, particularly Hα.‡ It is superfluous to say that very good results were got. The feature that marks them in comparison with what was done elsewhere is in my judgment less than the advantage given by greater instrumental power or better atmospheric conditions (it is easily possible to exaggerate these) than the plan to examine methodically the behaviour of high levels such as give genesis to the hydrogen lines as well as low levels marked by lanthanum and cyanogen, alongside the mean results. The investigation becomes more than an inquiry into surface drift; it is a sounding of the Sun's atmosphere. To derive trustworthy measures from the line Hα is no small feat, no matter what resources you have, but Adams's conclusion seems abundantly proved that the hydrogen strata rotate everywhere faster than the strata below, and that Carrington's decrease of motion from equator towards the poles has at their level largely disappeared. Comprehensive theories of the Sun are at present, I suppose, in the lumber room. When the time comes to bring them out again, this fact will be a very awkward feature to find a place for.

It will not, I hope, be written down to partiality if I express the view that the advantages of climate and equipment possessed by Mount Wilson by no means rob their full value from the other parallel researches. Debate is the healthy state for scientific questions. Where there is agreement it means, usually, somnolence. But we may say this, no one would now produce measures of the solar rotation without taking into careful review the way they stand in comparison with Adams's results.

Referring now to the group of papers which deal with stellar spectra, and first with those that deal with individual spectra of general or of particular interest, I shall not say much more than that they represent the notes of points of special interest which arise to vary the round of regular work. Many of them are in collaboration, first with Frost at Yerkes, afterwards with various members of the staff at Mount Wilson. Three of them relate to Novæ, namely, Nova Persei (1901) and Nova Geminorum No. 2, (1912) at the time of their discovery, and the third, which will perhaps be felt more characteristic of Mount Wilson work, is a

* *Ap. J.*, 26 (1907), p. 203.
† Publications of the Carnegie Institution of Washington, No. 138 (1911).
‡ *Ap. J.*, 27 (1908), p. 213.

review in 1914 of the spectra of four Novæ,* viz. Nova Aurigæ (1891), Nova Persei (1910), Nova Lacertæ (1910), and Nova Geminorum No. 2 (1912). At this date their magnitudes were respectively 14, 12·4, 12·5, and 10. With a single-prism spectrograph of 16 cm. length, at the Newtonian focus of the 60-inch telescope and a slit-width of ·062 mm., an exposure of sixteen hours was required to secure the first. It is a *tour de force* worth noting.

Several other papers are notes of individual stars or short lists of stars of variable radial velocity. In the early days of radial work the investigator did not do badly if his results succeeded in not flatly contradicting one another. We are now very far from that. In Adams's lists of 500 stars the probable error is generally less than 1 km./sec. Hence a discrepancy of a very few km. between the determination from plates at different dates becomes a strong presumption in favour of real variation of velocity, and such stars are marked for investigation as spectroscopic binaries, and possess an interest of their own as being a very large proportion—say one-third or more—of the whole, of shorter period than can usually be established with the micrometer, and when they also happen to be eclipsing systems, as offering very valuable information as to the *densities* of the stars.

One of the papers upon individual spectra should be noted, not so much from its contents as that it gives a foretaste of what we may look for in the future. This is the paper on the spectra of Sirius, Procyon, and Arcturus.† Among the original plans of Mount Wilson observation, large-scale spectra of the brightest stars had a place. This illustrates what was intended. The high-power spectroscope was employed, giving a spectrum up to Hα of scale approaching that of Higgs's solar spectrum. The purpose of so minute a study is to obtain knowledge of the conditions of atmosphere as to pressure, temperature, and so forth by examining the modifications undergone by the spectral lines. It may be said to start from an observation of Professor Hale's of the presence of sun-spot lines in the red stars.‡ The quantity of information contained in these spectra must be enormous. Naturally the treatment given in the first discussion is far from exhaustive. Some of the characteristic results may be mentioned. The spectrum of Sirius is of class A, that of Procyon F5 or approaching a solar type, while that of Arcturus is K. The three stars, therefore, would form a progression, according to the current view. It is found that in the spectrum of Sirius the enhanced lines which are very prominent are shifted distinctly towards the red relative to the arc lines, that the same feature in less pronounced degree is shown by Procyon, but for Arcturus it has almost or quite disappeared. Discussing Arcturus separately, Hale's remark of the similarity of its spectrum to a sun-spot is confirmed by the correspondence in the relative strengthening and weakening

* With F. G. Pease, *Ap. J.*, 40 (1914), p. 294.
† *Ap. J.*, 33 (1911), p. 64.
‡ *Publ. Yerkes Obs.*, No. 2, p. 129; *Ap. J.*, 23 (1906), p. 400.

of many different classes of lines; and it is shown that the elements hydrogen, calcium and magnesium, vanadium titanium and nickel, and iron fall into four classes, the lines of each being shifted measurably towards the red relative to the preceding. As to the explicit interpretation of these results, variety or reserve of opinion may be allowed. One can say that they appear to fit in quite well with views that are widely held as to the states of these stars; no one would hesitate to admit them as facts of the first importance and very difficult to arrive at.

I come now to a very important memoir on the radial velocity of 500 stars.*

The plan of this investigation included—

1. A and B type stars, mainly between magnitudes 5 and 6·5, a knowledge of whose motions is of particular interest as aiding in the determination of the elements of the two principal star-streams.

2. A, F, G, K, and M stars of magnitudes 5·5 to 6·5, which have very small proper motions. These may be regarded as very distant stars of high luminosity.

3. Stars with measured parallaxes, most of which have very high proper motions, of magnitudes from 5·5 to 8·5.†

Results require to be accumulated before they can be interpreted; this investigation belongs to the period of accumulation, and does not lend itself to summary description. I may, however, mention the following contribution to a question which is usually quoted as settled, namely, that of increasing radial, and presumably absolute, velocity with advancing stellar type. Adams gives the following comparison:—

Spectral Type.	Campbell.		Mount Wilson.	
	Proper Motion.	v' km./sec.	Proper Motion.	v' km./sec.
O and B	″0·031	8·99	″0·016	8·23
A	·094	9·94	·019	10·04
F	·234	13·90	·011	10·14
G and K	·202	15·15	·014	11·03
M	·074	16·55	·015	12·56

It will be observed that Campbell's progression is very much reduced when we pass to Adams's catalogue of more distant stars. A consideration of the way in which stellar drift would affect this table rather emphasizes its point, and Adams remarks that it seems to indicate that with very distant stars there is but slight change of velocity with spectral type.

Reviewing this great mass of work that I have imperfectly

* *Ap. J.*, **42** (1915), p. 172.

† One hundred stars belonging to the last heading had been published earlier in collaboration with Kohlschütter, *Ap. J.*, **39** (1914), p. 341.

described, it might seem that there was nothing to signalise it beyond technical excellence combined with great opportunities of equipment, and in the matter of technical excellence Adams to-day by no means stands alone. One might look for some single clue or master idea binding the whole together and fail to find it, for in his writings Adams is strictly an observer and recorder, and in the one or two cases where he offers an interpretation, he accompanies it with an apology for its speculative character. For that matter it is easy to attach too much importance to a master idea; too often it turns out upon examination to be a mere shell, capable of all kinds of meanings according to the contents that are put into it.

An investigator must make a flexible as well as a lucid plan, for he must always be prepared to change or discard it. We search for what we do not know, and we search essentially by instinct.

One might say generally that Adams's intention was to elucidate the stellar atmospheres. Such was the purpose of the paper on Sirius, Procyon, and Arcturus. Stellar atmosphere may seem a good long way from contributing to the parallax question to which I now come. But we must remember where the real strength of the spectrum, for astronomy, is found. In spite of the endless qualifications of which I have spoken so much, it is, in a certain sense, absolute. The distance-factor, where it affects stellar spectra at all, affects them in utterly different degree and law from the old geometrical astronomy. We may, therefore, succeed in confronting the geometrical distance-effect with an alternative measure, and so exchange the one for the other. Such an idea, in a more or less fluid state, is nothing new. Kapteyn, in a recent paper "On the Change of Spectrum and Colour Index with Distance and Absolute Brightness: Present State of the Question,"* enumerates from the unique magisterial position that all the world accords him the investigations required, and says, "A well-determined influence of absolute brightness, besides being important in a study of the physics of stellar atmospheres, would furnish the means of determining parallaxes where the other methods break down." Adams had already written a paper "On the Relative Intensity at Different Wave-Lengths of the Spectra of Some Stars having Large and Small Proper Motions,"† that is to say, allowing freely for individual exceptions, of stars at small or great distances. For distant stars, generally speaking, he finds that the strength of the spectrum is more in the red than in the blue. Whether this means absorption in space, or is a consequence of the much greater absolute magnitude of the distant star, does not at once appear. The matter is dealt with further in the pregnant paper to which I now come, namely, Adams and Kohlschütter, "Some Spectral Criteria for the Determination of Absolute Stellar Magnitudes."‡ One sees in this paper that though the general purpose is, as I said, not new, the way has still to be felt for a reliable method. The paper begins with a reconsideration of the continuous spectrum and

* *Ap. J.*, 40 (1914). † *Ap. J.*, 39 (1914), p. 89.

‡ *Ap. J.*, 40 (1914), p. 385.

its increasing intensity towards the red for distant stars. It is shown for a large number of stars that this effect increases as the type of star advances, from F to K. Hence at least a portion, possibly all, of this reddening of the very distant stars, proved in the previous paper of Adams, must be ascribed to the star's own atmosphere, and not exclusively to scattering of light in space. This is by the way. The kernel of the communication follows, in the relation of the intensity of spectral lines to class and to absolute magnitude. Systematic differences of intensity for certain lines between stars of large and stars of small proper motion had become evident in the course of classifying spectra. In order to secure an accurate system of classification, as well as to investigate these differences, pairs of lines were selected not far from one another in the spectrum, and as nearly as possible of the same intensity and character, and estimations were made of their relative intensities. A line decreasing in intensity with advancing type, such as one of the hydrogen lines, was compared with one which increases in intensity, such as an ordinary metallic line. Thus Hγ or Hβ was compared with five suitable metallic lines, numerical estimates made, and no systematic differences appearing, the mean of these numbers was accepted as the *measure* of the star's spectral type. The internal agreement of the method was found to be good and to yield a consistent numerical index of spectral class.

With regard to absolute magnitude, a number of other lines were taken which are strong or weak respectively in stars of high luminosity and show a change in the opposite sense as the luminosity is less. The relative intensities of the five most marked pairs were estimated and combined in a mean as before. This gave a numerical index of absolute magnitude, and using known absolute magnitudes to work from—defined as the apparent magnitude which the star would show at a distance of 10 parsecs—formulæ were derived, by which the index could be interpreted in any case. From these formulæ 162 stars were calculated. The average difference between these estimates and absolute magnitudes derived from measured distance was about 1·5 magnitudes, a result that was taken as showing that there appeared to be considerable promise in the application of spectrum-line criteria to the determination both of absolute magnitudes and of parallaxes.

This was the first stage, and I suppose it represents the degree of utility that the best friends of such a method would have anticipated for it—a method something on a par with the derivation of parallaxes from proper motions, reliable on the average, available when other methods failed, but in individual application honeycombed with large exceptions. That the writers themselves looked for nothing more is shown by the fact that they based their formula and made their comparisons indifferently with measured parallaxes and with theoretical parallaxes inferred from proper motions. The method, as Adams tells us, was devised in large measure by Kohlschütter. Kohlschütter, I understand, is a German officer, and would, I presume, at the present moment be

fighting against us in Germany's infamous ranks if we had not captured him on his way from Mount Wilson. Let me not, for that reason, seem to deny any prestige that may be his due—the uncertain, poor, treasured reward of the scientific worker.

Since his departure the method has been applied at Mount Wilson with little modification, but the work has been greatly extended with the aid of additional material available. The result is to put it upon an entirely different level.

It is worth while to pause a moment and consider what is the essence of the change introduced. It is seen best in the matter of the classification. The Harvard classification, which the new one does not displace, was itself intended to be as arithmetical as it was wise to make it, the transition from class to class being measured in tenths, estimated from the intensities of certain lines. But it was with the same lines in other spectra, not with other lines in the same spectrum, that the comparison was made. It would be difficult to overrate the value of this small change. It makes the circumstances of comparison identical. It turns a descriptive classification into a physical arithmetical measure. Now arithmetic is the final stage of science. One is justified in anticipating for it an almost incalculable increase of power in the future, as is illustrated already by the rapid progress made since it was devised.

In place of a general adjunct to other resources by which we could infer distance, the method has been shown by Adams to be as precise as first-class direct measures. Where an agreement in magnitude of about 1·5 magnitude was at first regarded as satisfactory, it now predicts individual parallaxes with an average deviation from the independent measures of one-fortieth of a second of arc.* This great advance in effectiveness may be ascribed largely to a more thorough treatment. The material available for discussion consists of several thousand spectra. One difficulty of the first discussion, and in part of the second one, was the want of parallax determinations of distant stars. It was natural for parallax observers to desire that their results should not be, predominantly, null, and therefore they have confined themselves to stars which there was reason to believe were not too remote. This want was partly filled by observations by another of the Mount Wilson observers, Mr. Adrian van Maanen, of parallaxes of certain stars of small proper motion, and by the Yale observation of the very bright stars. Another change made is to confine attention to two varying lines alone, one of which increased while the other diminished in intensity with progressive type. Looking back, these lines seem now a fairly obvious choice. One is the line $\lambda 4216$ *Sr*, an enhanced line, that is, probably, a high temperature line, prominent in the solar "flash" spectrum and upper chromosphere. This line recedes in intensity as the type of the star advances. It was compared for intensity with an iron line that is closely adjacent. The other

* *National Academy of Science, U.S.A., Proceedings*, vol. ii. (1916), pp. 147, 152.

is the line λ4455 *Ca*, which in the solar spectrum is greatly strengthened in sun-spots, and increases in intensity with decreasing temperature. This was compared twice over, first with an adjacent line λ4462, which is a blend of *Fe* and *Mn*, and as a corrective with the line λ4495 *Fe*. All the stars of measured parallax were then collected for which spectral observations were available. They were divided into two blocks. From the first the formulæ connecting absolute magnitude with difference of intensity of line was derived, for the second the same formulæ were used to predict the absolute magnitude and thence the parallax. Agreement in the former group between calculated and observed parallax shows only the adequacy of the simple formulæ employed to represent the data. The mean discrepancy is ±0″·024. The second group is pure prediction. The mean discrepancy is ±0″·026. There are 58 stars in the first group, and 63 in the second. The spectral types range from Fo to Ma, and the magnitudes from 0·2 to 9·3.

To illustrate further the flexibility of the method and its application to other researches, it is shown * how clearly these criteria separate the stars of class M into two groups of high and low intrinsic brightness, supplementing most admirably the indications of "giant" and "dwarf" stars derived from measured parallaxes.

Writing in 1912, Gill quotes from Schlesinger's account † of his observations for parallax with the Yerkes telescope :—"The number of stellar parallaxes that can be determined per annum with an average probable error ±0″·013 will in the long run be about equal to the number of clear nights available for the work"; and adds, "How great this advance is, only those who have determined parallaxes of like accuracy with inferior means can fully realise." This is a standard that is still a high one. To the majority of the parallaxes used in constructing and testing Adams's formulæ, the *whole* of the apparent error of a fortieth of a second of arc might be attributed without violence. We have, then, a method which will turn a star's parallax out with the same accuracy as the best direct measures, as a bye-product of its spectrum, by mere comparison of the relative intensity of a few of the lines and at the cost of a negligible calculation. I suppose it is not too much to expect that in a very short time the Mount Wilson observers may give us the absolute magnitudes and spectral parallaxes of some thousands of stars whose distances have never been measured. Nor in a very short time shall we hesitate to believe as confidently in these as in direct measures. For I think one is not less surprised that the measured parallaxes are reliable enough and so free from systematic errors as to stand such a recalculation, than that it should be possible to find a method of recalculating them in detail.

A few further general remarks upon the method, its limits

* *Nat. Acad. Proc.*, vol. ii. (1916), p. 157.
† *Monthly Notices*, lxxii. (1912), p. 326.

and prospects, may not be out of place. I have described the method in terms of the familiar notion of parallax, but parallax has essentially nothing to do with the matter, except to supply attested examples of absolute magnitude from which the coefficients of the formulæ may be determined. Once the formulæ are established, the examination of the spectrum gives the absolute magnitude of a newly observed star directly and without mediation of geometry. If the distance is what interests us, we deduce it by help of the apparent magnitude. Briefly put, we look at a star and say how big it really is, irrespective of distance. We can rebut Shakespeare's scoff of

> the star . . . .
> Whose worth's unknown although his height be taken.

It has been described to me as a new door into the universe, and the language does not seem immoderate.*

At present it applies only to spectra from classes F to M. This is a limitation which one will look confidently to see removed when sufficient study has been given to reveal corresponding features in the stars of earlier type. As to the range of distance that can be explored there is, strictly speaking, no limit, provided only the star is bright enough to record its spectrum.

One may reflect how dependent the method is upon a sound, well-determined scale of apparent magnitude. The subject of magnitude has been isolated, and has sometimes been regarded dubiously as barely scientific in conception.† Great pains have been spent nevertheless upon rectifying it, and it now comes into its own as the indispensable link uniting geometrical and spectroscopic astronomy.

One remark I would throw out at hazard for what it may be worth. Many of the spectra used were of very moderate dispersion. No comparison spectra are required. It is not apparent that the power of the 60-inch telescope, or even a narrow slit with its great loss of light, are in any way essential for success. If this is so, the method brings a vast quantity of work of the first importance within the reach of very moderate equipments.

I have now completed my description of our medallist's work, and I think the Society will rest satisfied that our award is well bestowed. Brilliance and patience, the provision of adequate means and the adaptation of means to the end of producing ordered knowledge,—by one or all of these qualities not a few American astronomers have given the world in our own generation an unsurpassed model of research. The direction of such research to really necessary objects will, as a rule, preclude a man from seeking primarily striking results for himself, not least so when he is part of an organisation whose mere healthy working produces almost automatically more problems than any individual can cope with.

* In the address as delivered there was an error at this point which I am indebted to Professor Turner for pointing out.

† Cf. *Carte Phot. du Ciel, Réunion de* 1909, Procès-verbeaux, p. 43.

He works, and he gets and gives ideas. It would be a mistake to say that their value lies in their genealogy, or in their momentary shape, or in their working out. The three are inseparable. Without dwelling upon this, the right man finds a contented reward for his work in its conscious thoroughness and worthiness. Not less do we rejoice when it leads in direct line to some signal advance. Our medal bears two mottoes, both of good ancestry: *Quicquid nitet notandum*, which we take from Herschel, and *Nubem pellente mathesi*, from Halley's encomium of Newton. I think you will agree that both of them are particularly appropriate to the comparatively short but full record of our medallist that I have endeavoured to describe to you.

Addressing the Foreign Secretary, the President said:—I ask you to convey this Medal to Mr. Adams with the good wishes of the Society for his health and continued activity. Many here are his personal friends, still more know and value him only from his writings. All unite in their appreciation for what he has done.

The Meeting then proceeded to the election of the Officers and Council for the ensuing year, when the following Fellows were elected:—

President.

Major P. A. MacMahon, D.Sc., Sc.D., LL.D., F.R.S.

Vice-Presidents.

Sir F. W. Dyson, M.A., LL.D., F.R.S., Astronomer Royal.
A. S. Eddington, Esq., M.A., M.Sc., F.R.S., Plumian Professor of Astronomy, Cambridge.
H. F. Newall, Esq., M.A., D.Sc., F.R.S., Professor of Astrophysics, Cambridge.
R. A. Sampson, Esq., M.A., D.Sc., F.R.S., Astronomer Royal for Scotland.

Treasurer.

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A. C. D. Crommelin, Esq., B.A., D.Sc.
Alfred Fowler, Esq., F.R.S., Professor of Astrophysics, Imperial College of Science and Technology.

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W. H. Maw, Esq., LL.D.
J. W. Nicholson, Esq., M.A., D.Sc., Professor of Mathematics, King's College.
Rev. T. E. R. Phillips, M.A.
A. A. Rambaut, Esq., M.A., D.Sc., F.R.S., Radcliffe Observer.
J. H. Reynolds, Esq.
H. H. Turner, Esq., D.Sc., D.C.L., F.R.S., Savilian Professor of Astronomy, Oxford.